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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Plastics Shipbuilding

U.S. Department of Commerce
Maritime Administration

in cooperation with

Todd Shipyards Corporation

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FOREWORD

This is one of the many projects managed and cost shared by Todd Shipyards Corporation as part of the National Shipbuilding Research Program. The Program is a cooperative effort between the Maritime Administration's Office of Advanced Ship Development and the U.S. shipbuilding industry. The objective, described by the Ship Production Committee of the Society of Naval Architects and Marine Engineers, emphasizes productivity.

The research effort was assigned by subcontract to Springborn Laboratories, Inc. (formerly DeBell & Richardson) after evaluation of several proposals. J. A. Melchore was the researcher. P. T. Whiting of General Dynamics, Quincy Shipbuilding Div., participated as a ship design and construction consultant.

In behalf of Todd Shipyards Corporation, Seattle Division R. F. Heady was the R&D Project Manager who provided technical direction. J. F. Curtis participated in the final editing effort, and L. D. Chirillo was the R&D Program Manager having overall cognizance.

Appreciation is expressed to the following for their constructive criticism of the manual in its draft form: R. A. Babcock of General Dynamics, Quincy Shipbuilding Div., J. C. Daidola of M. Rosenblatt & Son, Inc.; T. F. Robinson of Bethlehem Steel Corp., Central Technical Division; C. J. Starkenburg, J. W. Peart, T. H. Doussan and O. K: Tilley of Avondale Shipyards, Inc.; G. A. Uberti of National Steel & Shipbuilding Co.; LCDR G. L. Rowe of the 12th Coast Guard District (mmt); D. F. Smith of Lockheed Shipbuilding & Construction Co.; and E. Homer of Vancouver Shipyards Co. Ltd.

EXECUTIVE SUMMARY

If the 19th century transition from wood to iron had not taken place and if shipbuilders were now confronted with steel for the first time, it's plausible that some would say: "Steel ships—you've got to be kidding! Steel is heavy and it rusts like hell in seawater. What's more it's a conductor—we already have enough grief from electrocutions, grounds and electrolytic action. We would need a lot more energy for cutting and welding. Besides, with welding glare and fumes plus gouging and fitting noise, there is no way OSHA would approve!" But more knowledge would disclose the advantages which justfy steel as the prime structural material in ships.

While plastics have been introduced, their use is very limited compared to their potential for improving shipbuilders' productivity. As in the example given above, assessment of a proposed application is frequently curtailed by tradition or lack of understanding of available data. Similarly, more knowledge about plastics will disclose facts which will justify their greater use in ships. Unlike steel, plastics: are light in weight, do not "rust like helI in seawater" nor in certain acids, are nonconductive but can be made conductive, are less energy intensive, and do not impose in-process problems with glare, fumes and noise.

More knowledge will disclose tremendous recent developments in composites, i.e., the use of graphite or boron fibers to combine the strength advantages of metals with the unique advantages of plastics. Developing fiber winding techniques permit both the magnitude and alignment of strength properties to be matched to specific requirements. Further any innovation that causes a net decrease in requirements for manpower, materials, facilities and time improves productivity. More knowledge will disclose that plastics, fiberglass pipe for example, can result in a decrease in all four of the resource categories simultaneously.

Thus, this report is intended to assist shipbuilders, owners and regulators to acquire a better understanding of plastics. When such knowledge reaches a sufficient level, like that which is now generally known about steel, opportunities for greater productivity could be realized from the use of plastics.

It should be kept in mind that this report is inhibited by the tendency of the shipbuilders interviewed to compare potential applications of plastics to metals, steel in particular. With more familiarity, shipbuilders will begin to think of new applications that are based only upon matching performance specifications to the unique properties of plastics.

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1.0 INTRODUCTION

1.1 Purpose and Scope

The objective of this study was to facilitate increased use of cost effective plastics and reinforced plastics in the U.S. shipbuilding industry.1

Literature was searched for applications in shipbuilding and related industries. Ships were visited, and naval architects, shipbuilders, regulatory agencies, and polymer suppliers were interviewed to discuss their experiences with plastics and their ideas for extended use.

The product of this study is this manual for shipbuilders which:

- contains fundamental knowledge about plastics,
- points out their advantages and limitations, and
- explores selected applications of plastics which have the potential for greater productive use.

1.2 *The Value of Plastics*

1.2.1 General

The plastics industry has grown over the last 30 years to be a very matured and involved business with applications varying from the most simple parts to sophisticated assemblies. Sales in plastics for 1976 reached 29.4 billion pounds distributed over many major industries, e.g.:

Use Area	*Billion Lbs.*
packaging	6.4
building/construction	5.2.
electrical	2.3
transportation	1.8
housewares	1.4

Plastics are no longer just substitute materials. On a cost/performance basis they can outperform conventional materials in many applications. And, plastics have made certain applications possible which were not feasible with other materials. Plastics facilitate freedom of design and reduction in the number of components needed in an assemblage. Frequently, an assembly consisting of more than one die cast pat is replaced by a single molded plastic part which requires little or no finishing. Plastics are already used extensively in all forms of transportation, e.g., cars, trucks, buses, trains. airplanes, etc. In 1976 plastic usage per car was 190 pounds, it is estimated that it will be 230 pounds in 1980 and by further replacing metals it will be as much as 500 pounds by 1985.[2]

Plastics are heterogeneous in species, more so than any other materials used in shipbuilding. They are organic compounds of many types which are quite different in chemical structure from each other. Within each generic type, formulations can be modified to render slight to major differences in processability ard/or physical properties. The modtications may be brought about by basic molecular changes in a polymer per se or through additives which serve as catalysts, lubricants, anti-oxidants, fillers, reinforcers, flame retardants, anti-static agents, low shrinkage agents, etc. Thus, the characteristics of the almost infinite number of formulations cannot be covered within the scope of this study. However, to the extent that it is practicable, properties for generic types are discussed in Section 5.2 and are tabulated in Appendix A as a reference for designers.

1.2.2 *Why Plastics Are Used*

The reasons why plastics are so successfully used today may be easily overlooked unless the requirements for their applications are analyzed. Through judicious selection of a plastic, one or a combination of the following properties, among others, are obtainable:

impact resistance (toughness)
chemical resistance
electrical resistance
low specific gravity
dimensional stability
low cost
self-extinguishing
high Young's modulus (through filament winding, cross laminating, or use of high modulus fiber).

'The use of plastics to insulate liquid natural gas tanks was excluded because it has already received great attention and is in implementation. Also, the subject of plastic coatings such as for ships' bottoms was excluded because it belongs within a research category which is separately sponsored by the National Shipbuilding Research Program. i.e., Surface Preparations and Coatings.

2"Funsre Shock in Detroit," Newsweek. August 8. 1977, pp 68-69. Also predicted is ". . soft front and rear ends made of urethane or reinforced plastic that won't dent or scratch" and if costs can be reduced graphite reinforced plastic for ". . drive shafts, springs, doors and bumpers,"

1.2.3 Limitations

While plastic composites can be made to have specific strengths that exceed steel,[3] high costs limit their application to situations where weight is a prime concern. This will rarely occur in merchant ships but does occur in naval vessels, aircraft, missiles, etc.

Plastics cannot be classified as incombustible. That is, plastics will bum in a flame source. Thus, they are not permitted everywhere in ships. But, plastics can be made self-extinguishing so that they cease burning when the flame source is removed.

Plastics vary in the amount of smoke and types of toxic substances generated during fires, as do all other organic materials. Therefore care must be exercised in choosing the appropriate plastic for a specific application. The National Bureau of Standards (NBS) is identifying such decomposition products and setting standards as to permissible limits. The standards are not expected to be published before 1979.

The maximum recommended continuous use temperatures for plastics usually vary from 140°F to 300°F depending upon *the generic* type involved. Plastics are widely used outdoors in temperatures as low as minus 40°F or even lower for some specific uses. Federal standards require retention of physical properties at temperatures as low as minus 60°F.

If a fabricating mold is required, the number of plastic units to be cast must be sufficiently high to amortize the mold cost. But some plastic products can be fabricated with low cost tooling.

1.2.4 *Cost and Availability*

Pricing for basic material varies from 30¢ to $1.50/lb with some of the high modulus products selling in excess of $25/1b.

As to cost stability, plastic prices increased 8-12% during the oil embargo and have since increased 3-5%/year. A 5-6%/year price increase is anticipated through 1980 with no anticipated shortages.

Because producing metals is more energy intensive than for producing plastics. wider swings in metal prices were noted over 1974-1976. Metal suppliers" are estimating a 5-7%/year price increase through 1980.

1.3 *Search for Plastics in Shipbuilding*

1.3.1 Search Effort

A number of sources were searched for past. present and potential applications. The initial effort consisted of scanning a massive computer indexed collection of technical literature for the period 1964- 1974.[4] This produced hundreds of references to plastic applications in special performance craf but virtually nothing that would productively impact upon any cost category in shipbuilding per se. The researcher's library, which supplies information on plastic materials, processes, and worldwide markets, was searched with similar results..

The literature searches were supplemented by numerous consultations with ship designers, shipbuilders and individuals representing the U.S. Coast Guard (USCG), American Bureau of Shipping (ABS). U.S. Navy, Maritime Administration and the NBS. The ideas thus acquired were then further discussed with polymer producers and fabricators.

1.3.2 *Findings*

Because of its great cost/performance advantage. shipbuilders will continue to use steel as the prime structural material. For other shipbuilding applications. selected plastics do economically compete with metals and even outperform them in certain services.

Because plastics are organic, they cannot pass the test specified by the USCG[5] for incombustible materials. However, plastics can be made self-extinguishing, i.e.. when a flame source is removed the plastic ceases to burn. An estimated 4.5 billion pounds per year of self-extinguishing plastics comply with various codes for buildings, appliances, automobiles, urban transit. aircraft, etc.

In fires all plastics, like other organic materials, give off smoke and toxic substances in varying degrees. Thus. diligence is required to select plastic types for specific applications based upon factual data such as that being prepared by the NBS.

In U.S. built ships, plastics are established in thirteen applications, see paragraph 4.2.1. Some are fiberglass stall showers, vinyl clad joiner panels, epoxy chocks and modular staterooms with vinyl surfacing and complete fiberglass bathrooms. A total of forty-six other applications are listed and classified for their interest to shipbuilders. see Table 6.1.

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[3]See .. Advanced Composite Materials." H. R. Clauser. Scientific American. June 1973, pp 36-44.
[4]Performed by Western Research Application Center. University of Southern California. Los Angeles.
[5]46 CFR 164.009, this notation. used throughout this manual. identifies a specific passage in the USCG administered Code of Federal Regulations. All such references are those in effect on 15 August 1977.

Although plastic propellers of small size have been tried with mixed results, a consensus of ship propeller designers believe that a large diameter. slow speed propeller made as a plastic composite is worth further investigation at this time.

No ideas new to shipbuilders for plastic applications resulted from the search.

1.4 *Conclusions*

1.4.1 General

The shipbuilding industry's conservatism regarding plastics results from routinely following the regulations spelled out by the USCG. There has been limited pioneering on a ship designer's part to risk a new concept even though it could result in reduced building costs. Further. there is relatively little interest on a polymer supplier's part to foster plastic usage in ships because it is a relatively small market characterized by uncertainty about the increased potential for plastics. Thus the naval architect, the polymer supplier and the regulators rarely become involved in prerequisite exchanges of information. To take fuller advantage of plastics the shipbuilder must solicit the cooperation of polymer manufacturers and must initiate requests for additions and/or changes to the USCG and ABS rules.[6]

1.4.2 *Cost Effectiveness of plastics*

The estimated costs savings for some applications of plastics as compared to conventional ship construction are:

Application	***Savings/Ship***[7]
Fiberglass Cargo Piping (less pump room)	$60.000[8].
Fiberglass Ballast Piping	$22,000[8]
Epoxy Chocking Compounds	$15,000
Substitution of Vinyl for Melamine on Clad Joiner Panels	$12.000
Fiberglass Stall Showers (20 units)	$5,000

1.5 *Recommendations*

1.5.1 Development of performance standards is recommended for plastic pipe system components and chocks for aligning machinery. The standards should categorize all performance criteria. e.g. anticipating installation. tests and service in ships. and including aging. fire and flood. But criteria for generation of toxic gases and smoke should be deferred pending completion of the current applicable NBS program.

1.5.2 Preparation of test specifications is recommended. Each of these should be separated into categories which match the categories in the aforementioned performance standards and should describe practical tests for assuring the acceptability of plastic pipe system components and chocks.

1.5.3 Submittal of a shipbuilding industry request to the USCG and the ABS is recommended for the inclusion of the aforementioned standards and tests in their rules. These requests should be accompanied by proposed wording for the rules which would definitive approved use of plastic pipe and chocks in specific systems, compartments, etc.

1.5.4 A study is recommended. with a $20,000 level of effort, for developing fundamental data that could prove the feasibility of a plastic composite ship's propeller because potential savings of $90,000 are estimated for a 27-foot diameter propeller.

1.5.5 Submittal of a shipbuilding industry request to the USCG is recommended to permit the installation. for certain systems, of plastic and reinforced plastic pipe behind paneling similar to existing provisions for electrical cable.

‘One shipbuilder commented that there is a need for owners. designers and shipbuilders to unite in submitting proposals for regulations which would permit safe and productive applications of more plastic products. He added that ". . builders must pass the savings on to owners and be prepared to give a fixed price reduction at the time of bidding. If the owner can buy a ship for less money and is convinced he is not sacrificing quality he can be a powerful force for change...

A 90.000 DWT tanker.

From "Fiberglass Reinforced Piping for Shipboard Systems" National Shipbuilding Research Program Report dated August 1976.

‘Pipe anchors and supports should be included in addition to pipe and basic pipe fittings. Because they are inherently more productive flexible pipe **couplings of the compression or slip-on type. such as Dresser Style 38 with removable stops to prevent creep. should definitely be included. In addition. a** performance standard should be included for applications where the pipe internal pressure is less than its external pressure.

2.0 PROMISING PLASTICS APPLICATIONS IN LIMITED SHIPBUILDING USE

2.1 Fiberglass Pipe [1]

Over 50 million feet of fiberglass pipe is produced annually in the United States for use in chemical plants, oil fields, refineries, etc. But, from the outset of this study it was apparent that although fiberglass pipe had been introduced in ships over 10 years ago, its usage remains limited compared to its potential for more productivity. This is due to the limited knowledge possessed by designers, owners, regulators and shipbuilders regarding the use of specific plastics in specific applications.[2] Thus, a concurrent study was made to focus on only fiberglass pipe in a merchant ship.

2.1.1 Investigation by a Shipbuilder

Fiberglass and steel pipe were compared in certain sections of both the clean ballast system and the cargo oil system in a 90,000 DWT tanker. Some deck piping for the cargo oil system was included. Although the study was separately published,[3] portions of its objectives and findings are quoted for the reader's convenience.

- *Objectives*

"... investigation into the possibility of a cost advantage . . . by substituting fiberglass . . . piping in place of steel for certain systems in an oil tanker."

"... to recommend further steps that might be taken to introduce fiberglass piping systems for general use in merchant ships."

- *Findings*

"Minimum savings to the shipbuilder by installing fiberglass cargo oil piping. . . exclusive of the pump room is 15%. . . This percentage savings is conservative . . . Savings will increase as the shipyard gains experience. . . The percentage will increase further by improved . . . design techniques which maximize . . . factory prefabrication."[4]

". . . saving for a fiberglass clean ballast system is . . . 20% . . ."

"There are no design or installation problems that would prohibit the application of fiberglass piping to selected fluid systems . . ."[5]

"No capital outlay is required. . . No specially skilled craftsmen are needed."

Because flexible pipe couplings of the compression or slip-on type, such as Dresser Style 38 with removable stops to prevent creep, are inherently more productive investigation should be made to determine ". . . the availability of coupling diameter sizes to match the fiberglass piping outer diameter. . ."

The pipe was filament wound using fiberglass and epoxy resin according to an ASTM standard.[6] The tabulated comparative costs, i.e., for steel vs. fiberglass pipe, from this study are presented herein as Table 2.1.

These findings, which are meaningful to shipbuilders, result from the close cooperation of a shipbuilder with a fiberglass pipe manufacturer (i.e. National Steel & Shipbuilding Co. and Ciba-Geigy Company).

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[1] Fiberglass". is defined as glass in fibrous form. However. the word is commonly used to denote a composite material consisting of a thermosetting resin reinforced with fibrous glass. This composite is also called glass reinforced plastic'. (GRP) or "fiberglass reinforced plastic" (FRP). Because there are fibers other than glass, ASTM pipe standards and recent USCG correspondence use the term "'reinforced thermosetting resin pipe" (RTRP).

[2] USCG thinking as of mid 1977 is contained in Appendix B.

[3] National Shipbuilding Research Program report .'1. Fiberglass Reinforced Piping for Shipboard Systems. 2. Discussion of Results from the Navy's Investigation of Filament-wound Fiberglass Pipe" dated August 1976.

[4] Shtpbuilders' comments varied. One stated ". . .there are substantial savings . . . material handling manhours are greatly reduced due to the light weight and also because welders are eliminated..' Another minimized handling benefits while agreeing that fiberglass pipe becomes". . . somewhat more attractive. . ." if sufficient qualified welders are not available. The latter also noted that fiberglass pipe is less flexible in making field modifications. This is so for large diameter pipe. Installations have to be more perfectly planned. Such planning is easy for some areas. e.g.. for deck pipe and for systems in the relatively smooth surfaced cargo tanks in double-bottom tankers.

Another comment regarded fiberglass as susceptible to damage during handling. installation and after installation. This is true for certain plastic materials used for relatively thin walled pipe. But. it is also true for thin walled pipe made from brittle or soft metal alloys. A standard which would specify minimum strength characteristics for fiberglass pipe would provide the necessary assurances.

[5] The Coast Guard may require that reinforced thermosetting resin pipe (RTRP) .". . . not be used in a concealed portion of any piping system. . ." See "installation Requirements' in Appendix B. A similar restraint in the existing Regulations applies only to polyvinyl chloride (PVC) pipe and is reported by one shipbuilder to be the main reason which precluded its use. Yet the Regulations. 46 CFR 111.60-25. permit installation behind paneling of electric cables which could have jackets and insulation made from the same generic Plastic materials. The Coast Guard should be requested to permit the installation of PVC pipe and RTRP behind paneling for specific systems.

[6] American Society for Testing and Materials D 2310.' Machine-Made Reinforced Thermosetting Resin Pipe.'.

TABLE 2.1 *Comparative Costs of Steel and Fiberglass Systems* *(as of May* 1976)

YSTEM	ACKAGE	DESCRIPTION	STI L SYSI						IBERGI SS SI :H						TOTAL $ IIFF.	IIFF.
			PING		SUPPORTS		MISC	TOTAL	PI NG		SUPPORTS		MISC	TOTAL		
			ATL $	ABOR $	MATL	ABOR	M & L	M & L	MATL $	LABOR	MATL $	LABOR $	M & L	M & L		
ALLAST IN D.B. IK #5	A	10" PORT BALLAST LINE	2006	4201	34	459	33	6733	1527	1250	55	565	636	4043	(2690)	(40)
	B	10" PORT BALLAST LINE	2118	4430	34	459	33	7074	1527	1250	55	565	636	4043	(3031)	(48)
	C.	10" PORT BALLAST LINE	2186	3925	34	459	33	6637	1527	1250	55	565	636	4043	(2594)	(39)
	D	10" STBD BALLAST LINE	2006	4201	34	459	33	6733	1527	1250	55	565	636	4043	(2690)	(40)
	E	8" TANK SUCTION	330	184	9	30	6	559	457	378	35	134	181	1183	624	111
		SUBTOTAL	8646	16941	145	1866	138	27736	6565	5378	295	2394	2725	17355	(10381)	(37)
ARGO OII IN #4 P, ,C TKS	A	30" PORT C.O. MAIN #4 TKS	5679	7149	295	5361	55	18539	8045	3387	309	1344	986	14071	(4468)	(24)
	B	18" & 8" CO/STRIP PORT SUCT.	1587	1955	105	687	55		1895	1304	42	323	1255	4919	530	12
	C	18" & 8" CO/STRIP STBD SUCT.	1838	2566	106	687	55		2229	1385	73	470	1282	5439	187	3
	D	30" STBD CO SUCTION MAIN	5679	7332	295	1588	55	14949	7246	2299	309	1344	946	12144	(2805)	(19)
	E	18" #4 CTR CO TK SUCTION	2002	2932	111	871	55	5971	2585	1198	55	403	1221	5460	(511)	(9)
	F	24" AFT DROP LINE	4792	5743	324	1482	55	12396	7255	2772	311	1331	1069	12738	342	3
	G	24" FWD DROP LINE	2780	3299	98	306	38	6521	3587		142	658	682	6561	40	1
		SUBTOTAL	24357	30976	1334	09	368	68017	32941	13835	1241	5873	7441	61332	(6685)	(10)
ARGO OII ON DECK	A	24" C.O. MANIFOLDS	8514	10020	832	2520	110	21996	13910	3009	270	3589	1724	22508	512	2
	B	24" C.O. MAINS ON DECK	20629	27817	2029	8966	220	59461	2234	6455	2291	8535	2330	41955	(17506	(29)
	C	24" DROP LINES	2378	244	0	----	5	2627	1298	188	83	376	58	2003	(624)	(24)
	D	8" P. & S. F.A.S. LINES	627	2001	55	626	33	3342	1443	336	20	188	344	2331	(1011)	(30)
		SUBTOTAL	32148	39862	2916	12112	368	87426	3900		2664		4456	68797	(18629	(21)
		GRAND TOTALS	65151	87799	4395	24960	874	18317	7850	29199	4200	20955	14622	14748	356	(19)

NOTE Differences **shown in parantheses indicate higher cost for sleel system.**

.1.2 Investigation by the Navy

Because failures are likely to occur if fiberglass pipe is substituted for metal pipe ‘. . . without designing around its particular properties” the U.S. Navy conducted pertinent investigations. These included “. . . fittings and bonded joints in areas such as fire resistance, joint quality, fatigue performance, etcetera . . .“ and produced basic data useful for service up to 150 psi and 200°F. A paper.[7] describing results of the investigations. provides encouragement for future applications throughout the entire surface-ship fleet.

Further, the Navy’s impressive results were recognized as a substantial contribution “. . . to the knowledge needed to create assurances for safety that the USCG and the ABS must have.” Thus, a four task research project was recommended which would produce a performance standard for any reinforced thermosetting resin pipe and specifications for tests which would determine acceptability.[8]

2.2 *Chocking of Machinery*

2.2.1 General

For engines, reduction gears, generators, pumps. etc., the installation of metal chocks is a time consuming task. Much skill is required to measure, grind, and fit chocks to render proper alignment. Four readings (each corner) must be made on each and at least 75% of the chock’s surfaces must be proved to be in contact with the mating machinery surfaces, Further when a metal chock is removed for inspection. it has been questioned as to how well it fits when re-inserted. It has been said that occasionally the edges of a chock have been peened to satisfy a requirement for minimum acceptable clearances. All of these problems may be alleviated, with reduced installation costs, by thejudicious use of an appropriate pourable epoxy chocking compound. In addition plastic chocks eliminate the need for machining the base of the equipment.

Proper alignment of main machinery is very critical. The steam turbine may cost 1 to 3 million dollars while the gear train may cost 0.5 to 1.5 million dollars. Many manhours are required for alignment. For example. in a 90.000 DWT tanker. they may be as follows:

Main Turbine	***Man Hours***
machine foundations	260
fabricate. machine, and fit chocks	580
	840

Reduction Gear	***Man Hours***
machine foundation in place	640
fabricate. machine and fit chocks	1,180
	1.820

For diesel engines. vibration is relatively severe and reportedly metal chocks fret enough to require replacement. Epoxy chocks do not fret because they facilitate more uniform contact of the mating surfaces and because they have a significantly lower modulus of elasticity as compared to steel. As is well known, relative motion between similar metals will cause fretting. In the case of steam turbines the vibration is less severe and this type of wear is not a problem.

2.2.2 *Historv*

Epoxy chocking compounds were used as early as 1966 for aligning main engines in ships. In 1973 a 23,000 HP slow speed B&W diesel engine was set on epoxy chocks. By 1976 there were approximately 4,000 such installations worldwide. Most were in tugs having 3.000-4,000 HP engines.

In early 1977 a sterntube was set in a tugboat, built in a Canadian shipyard. using a poured resin compound.

Nine U.S. built steam turbine ships of 9,000-28.000 HP feature some steel chocks interspaced with epoxy chocks for their main reduction gears. While substantial savings in labor are derived from using epoxy chocks, the drive machinery manufacturers inferred that their warranties may not be honored if 100% epoxy chocks were used.

Recently, a ship operator had experienced difficulity with a steam driven drive train as manifested in misalignment. Reportedly, insufficient foundation stiffness was suspected. In order to save an estimated $150,000 by resetting the reduction gear on the reinforced foundation with only epoxy chocks. the ship owner and shipyard is said to have assumed the reduction gear “warranty.”

It is further reported that an owner specified epoxy chocks exclusively for the main reduction gear in a 60.000 DWT bulk earner recently built in Japan. As to steam turbines, only 11 installations are reported to have been made worldwide.

The American Bureau of Shipping (ABS) has approved use of epoxy chocks under specific diesel engines installa-

7“Glass Reinforced Plastic (GRP) Piping for Shipboard Applications” by G. F. Wilhelmi & H. W. Schab. Naval Engineers Journal. April 1977. pp 139-160: reprinted in Appendix C. Although the term ..glass reinforced plastic (GRP) pipe’” k used, it is very probable that the Navy will adopt the ASTM term ‘reinforced thermosetting resin pipe (RTRP).".

8Comments by L.D. Chirillo. Naval Engineers Journal. June 1977. pp. 74-75: reprinted in Appendix C.

tions. However. no request has been made to ABS to use epoxy chocks under a steam turbine or its drive train because of the previously mentioned conditions.

Epoxy chocks for ships" machinery have been more widely used in Europe than in the United States. Many have been installed during overhauls.

One U.S. shipyard reported an estimated 25% savings in labor to set electric propulsion motors and main thrust bearings using epoxy chocks exclusively. Another reported excellent results for setting auxiliary equipment such as a winch. This same yard installed a combination of both steel and epoxy chocks for the main reduction gear in a gas turbine propelled ship. And a third U.S. shipyard successfully used only epoxy chocks to align the gear case in a C-4 troop earner: the steel chocks which they replaced had failed.

2.2.3 *Cost Savings*

In planning the installation of twelve large diesel-generators. the U.S. Navy estimated that 480 feet of one foot wide epoxy chocking would save over $100.000 as compared to the cost of installing steel chocks.!'

The cost effectiveness of epoxy versus steel chocks as given by a manufacturer of epoxy chocking compounds is incorporated in Table 2-2.

While the absolute dollar savings which may be realized by epoxy chocks to set any one item are not great. the percent savings in all cases is high. averaging about 85%. If this holds for each item which must be chocked. savings for a ship's major and auxiliary machinery could be substantial. For instance. it has been estimated that 900 man hours could be saved by setting stem tube bearings with epoxy: at $8/hr.. $7.200 savings could be realized in labor.

TABLE 2.2 ***Typical Labor Savings Through Epoxy*** chocks(a)

	Man-Days		Savings		
Application	Conventional Chocking(a)	Epoxy Chocks(b)	Man-Days	%	Dollars (c)
Diesel Generators (six)	96	10	86	90	6,880
Steam Engine	75	8	67	89	5,360
Diesel Engine	60	3	57	95	4,560
Diesel Engine(d)	25	3	22	88	1,760
Steering Gear (Japanese)	15	1	14	93	1,120
Steam Turbine	12	3	9	75	720
Shaft Bearing	10	2	8	80	640
Shaft Bearing	6	2	4	67	320

(a) Estimated by a manufacturer of epoxy chocking compounds
(b) Actual
(c) Labor Put at $10/Hr.
(d) 25,000 HP

2.2.4 *Design Consideration*

Reduction gear manufacturers and shipyard personnel advised that no specification was available for the torque applied to holding-down bolts. It was stated that a sledge hammer is driven against a large wrench until the "ring" indicates adequate torque. Thus. it is difficult to state with certainty that epoxy chocks would suffice. Their wider use is dependent upon shipbuilders specifically defining applicable static and dynamic loadings.

Physical properties of a common epoxy chocking compound are expressed by the manufacturer as follows:

compressive strength	19,000 psi	ASTM D695
tensile ultimate	4,970 psi	ASTM D638
modulus of elasticity	533,000 psi	ASTM D695
shear ultimate	5,400 psi	Fed. Std. 406
hardness (Barcol)	35-40	ASTM 2583
heat distortion temperature	93°C	ASTM D648
Izod impact	6 in lb/in	ASTM D256

However. shipbuilders should insure that properties expressed in accordance with the following are also known and will facilitate meeting a machinery manufacturers alignment specifications:

- compressive strength (yield and ultimate)
- compressive modulus (elasticity)
- curing shrinkage
- creep resistance (static)
- fatigue resistance (dynamic)

It is emphasized that these properties must be determined for the maximum operating temperatures expected and for the anticipated working life of the installation.

It is further emphasized that in order to achieve the above properties the entire environment at installation. including the machinery contact-surfaces. must be at least 60°F. [10] The required curing time is inversely related to temperature. No modification of the formulation should be

[9] Mare island Naval Shipyard "Value Engineering News & View... May 1972.
[10] shipbuilder located in the Northeast reported that it is sometimes very difficult to achieve the specified 60°F minimum for relatively large and/or exposed machinery. Therefore *in* planning. resources are allocated for both steel and epoxy chocks to anticipate periods when cold weather can occur. A selection is made dependent upon weather conditions at the time of installation.

made to achieve a faster cure as it can change the physical properties of the cured epoxy. Therefore. if the cure time commensurate with at least 60°F cannot be scheduled the installation of epoxy chocks is not recommended.

It is recommended that a research project be conducted to establish the actual loadings on machinery chocks under static and dynamic use conditions. These data are not likely to be developed by either the drive machinery manufacturers or the suppliers of epoxy chocking compounds. Thus. it appears that shipbuilders will have to take the initiative to develop a required performance standard and an accompanying specification for testing epoxy chocking compounds. Further. the specification should require that test samples be representative of a given geometry for a specific chock application. Often, plastics including laminates will show higher values for the relatively thin sections specified in ASTM tests as compared to their abilities to bear loads when in thick sections.

2.3 *Joiner Bulkheads*

For many years asbestos filled panels, such as 'Marinite-36,' have been used for joiner bulkheads because of the following features:

- non-burning (flame spread = 0)
- fuel contribution (negligible)
- smoke (zero)
- non-toxic upon decomposition by fire
- load bearing
- relatively low cost

Surface finishing is done by simple painting or more commonly by bonding a very serviceable melamine laminate. such as 'Formica. to the Marinite board.

Drawbacks include:

- high density (heavy to handle)
- relatively difficult to saw
- supply has not always been predictable
- backing laminate is required to prevent warping
- OSHA'[11] requirements on handling of asbestos containing products imposes in-plant problems

Due to USCG requirements for structural fire protection. alternative panels manufactured from just plastics do not exist. However. the research identified panels with non-asbestos cores which are described in the following for shipbuilders' convenience.

Johns-Manville has recently introduced a new bulkhead panel material coded' Marinite XL. " This material is said to contain no asbestos. The properties for Marinite XL and 36 are quite similar except that Marinite XL is 24% heavier. Pricing of Marinite XL is said to be the same as for Marinite 36.

Hopeman Brothers offer a panel (said to be asbestos-free) which is called "Beta 200 Core Building Unit." Frigid-temp and Hauserman offer panels that contain no asbestos and which consist of gypsum boards sandwiched between two sheets of steel. They are currently being faced with a 7 roils thick vinyl sheet. Cost comparisons are difficult since data for similar installations at a given shipyard have not been obtainable. However. a comparison using information provided by joiner contractors is included in Table 2.3.

TABLE 2.3 ***Approximate Cost for Installed Joiner Bulkhead*** (as of May 1976)

Joiner Panel Composition	Type Joiner	Cost - $/Ft² Material	Labor	Total	Avg. Cost
Melamine/ Marinite	Liner	5.00	4.40	9.40	8.33
		4.75	2.50	7.25	
Vinyl/Steal/ Gypsum/Steel	Liner	5.00	2.00	7.00	6.30
		3.50	2.10	5.60	
Melamine/Stee/ Core/Steal	Liner	4.50	4.00	8.50	8.50
Melamine/ Marinite	Divider	4.00	4.00	8.00	8.43
		4.50	4.50	9.00	
		5.10	3.20	8.30	
Vinyl/Steel/ Gypsum/Steel	Divider	5.00	2.00	7.00	7.03
		5.50	1.50	7.00	
		5.10	2.00	7.10	
Melamine/Steel/ Core"/Steel	Divider	5.00	3.90	8.90	8.90

Supplier refers to product as 'non-asbestos:

As ofv June 1976. it was reported that approximately 95% of the Marinite joiner panels were clad with melamine laminate. Recently there appears to be a definite trend toward using a vinyl surface. which is significantly less costly. Such composite panels generally consist of: vinyl facing/steel/gypsum board/steel.

A 90.000 DWT tanker incorporates about 25.000 sq. ft. of joiner panels with a 50/50 split of liners and dividers. A comparison of costs for various types of joiner bulkheads is found in Table 2.4.

These data show a potential savings of $42.875/tanker when melamine/Marinite joiner panels are replaced with vinyl/steel/gypsum/steel panels. Besides initial costs. other

"Occupational Safety and Health Administration

TABLE 2.4 ***Comparative Costs of Joiner Bulkhead Systems***

Composition Of Joiner Bulkhead	Type Of Bulkheads	Sq. Ft./ Tanker	$/Ft²		Cost Per Ship (Dollars)
Melamine/Marinite	Liner	12,500	8.33	104,125	209,500
	Divider	12,500	8.43	105,375	
Vinyl/Steel/	Liner	12,500	6.30	78,750	166,625
Gypsum/Steel	Divider	12,500	7.30	87,875	
Difference	—	—	—	—	42,875*

*$12,500 of this is attributed to the substitution of vinyl for melamine.

advantages over the melamine/Matitiite panels include:

- ready compliance with OSHA (since no asbestos is present)
- easier to saw and install
- every panel can be separately removed at any time
- better sound barrier between compartments
- ready availability
- greater shear load 400 lbs vs. 200 lbs for Marinite panels (will hold moly bolts)

The vinyl/steel/gypsum/steel panel is USCG certified for B-15 rated bulkheads as specified in 46 CFR 164.008. The panel offers:

zero - flame spread
zero - fuel contribution
zero - smoke emission

Thus the new system offers many advantages over the conventional melamine/Marinite: however, one shortcoming of the vinyl facing is that it cannot take as much abuse as the melamine. Most abuse of the vinyl occurs during ship construction and not while in service. But, the problem is surmountable by better planning and nominal protective measures.

In summary a serviceable. readily installable joiner panel is available which eliminates the hazards of handling asbestos containing products. The savings for a 90.000 DWT tanker could average about $43.000 based upon 1976 cost data.

2.4 *Bathroom and Shower Stalls*

Recently modular bathrooms featuring plastic composites. preferred by owners because they are easy to maintain. have been approved for use in a class of tankers. Among the several suppliers, Theodore Efron Manufacturing has sold shower units for installation in container ships. A satisfactory specification. suggested by the manufacturer is incorporated as Appendix D.

Typically. the unit cost for a stall shower enclosure exclusive of the base receptor is:[12]

3 sided 32" *x 78 1/2%"* stall shower completely finished on the interior faces	$215.00
Dome for shower stall (optional)	$2.50
Door for stall shower (tempered glass)	64.30
	$331.80

Often a shower unit is installed in a comer so that two of its unfinished exterior sides are concealed and the third unfinished side is visible. Thus. a facing is required. Table 2.5 facilitates comparison of estimated costs based upon material and labor rates supplied by manufacturers and joiner subcontractors. Installed costs for a fiberglass shower unit is shown to be approximately 23% lower or about $273 less than a conventional melamine/Marinite installation.

Since joiner subcontractors usually manufacture and install conventional stall showers they cannot be expected to recommend an alternative. Few would say that an installed fiberglass shower would be less costly. However, there is at least one. Frigidtemp. which has facilities for fabricating fiberglass shower units.

A Navy study[13] yielded a cost comparison for 11 modular stall showers in a destroyer type ship. As shown in the following comparison, a 24% saving was estimated through the use of fiberglass:

	Street Metal	*Fiberglass*
Initial Cost/Unit	$ 200	$ 275
Maintenance Cost/Unit/Yr.	20	9
Life Cycle/Cost/Unit (Initial cost + 20 x maintenance cost)	600	455
Total (Lifecycle cost x number of units)	6.600	5.055
Weight/Unit (Modular Unit)	200 lbs	130 lbs
Total weight (weight/unit x number of units)	2.200 Ibs	1.430 Ibs

	Fiberglass vs. Steet Metal
Total .Cost Savings	$1.595
Unit Cost Savings	$145
Weight Savings	770 Ibs

[12]Per 1976 price list from theodore Efron Manufacturing Company, Chicago. Illinois.
[13]NAVSEC (6132) memorandum serial 158 dated 25 March 1974.

TABLE 2.5 ***Estimated Cost for Stall Shower Enclosures (Conventional vs. Fiberglass)***

Type of Stall Shower /Item	Material used	Material Cost (In Shipyard)			Labor Cost (In Shipyard)			Total Cost (Dollars)		
		Ft ^{2}	\$/Ft ^{2}	Cost/ Unit	Ft ^{2}	\$/Ft ^{2}	Cost/ Unit	Mater-ial	Labor	Total
CONVENTIONAL DESIGN (32" x 36" x 75.5")										
Enclosure (2 sides)	Melamine/ Marinite	37.1	4.25	157.68	37.1	4.00	148.40	157.68	148.40	306.08
	S. S. Wings	19.6	5.00	98.00	19.6	4.00	78.40	98.00	78.40	176.40
	Gasketing (Corner)	-	-	10.00	-	-	8.00	10.00	8.00	18.00
Ceiling	Melamine/ Marinite	8.1	4.25	34.43	8.1	4.00	32.40	34.43	32.40	66.83
Curtain & Rod	Vinyl Curtain Curtain Rod	-	-	20.00	-	-	8.00	20.00	8.00	28.00
Base Receptor	Terrazo	8.1	7.56	61.24	8.1	4.00	32.40	61.24	32.40	93.64
TOTAL		-	-	381.35	-	-	307.60	381.35	307.60	688.95
FIBERGLASS DESIGN (32" x 36" x 78.5")										
Enclosure (3 sides)	Pre-Fab Fiberglass Enclosure	56.9	3.78	215.00	-	-	8.00	215.00	8.00	223.00
Decorative Panel for 1 Unfinished Exposed Side	Melamine/ Marinite	19.6	4.25	83.30	19.6	4.00	78.40	83.30	78.40	161.70
Dome for Stall	Fiberglass	-	-	52.50	-		-	52.50	-	52.50
Curtain Rod	Vinyl Curtain Curtain Rod	-	-	20.00	-		8.00	20.00	8.00	28.00
Base Receptor	Fiberglass	-	-	63.50			4.00	63.50	4.00	67.50
TOTAL		-	-	434.40			90.00	434.30	98.40	532.70

3.0 POTENTIAL APPLICATIONS

This section deals with applications which are either in very limited use or not in use but worthy of further consideration because of potential savings.

3.1 *Propellers*

A 27-foot diameter constant pitch nickel/aluminum/bronze alloy propeller costs about $250,000 and weighs 55 tons. With the metal alloy at 90¢/lb material alone amounts to $99,000 or 4% of the finished propeller cost. The foundry process and extensive grinding to meet tolerances are both labor intensive.

3.1.1 *History*

As early as 1937 development work had begun on fabricating plastic propellers. The first attempts were made to construct ship and aircraft propellers of “Textolite.” They were built with diameters of 420 mm (1.4 ft) and 630 mm (2 ft) but it was shown that the material quality was not satisfactory.

The earliest polyamide ships’ propellers were built both in Europe and America. They were lightweight. good at damping vibration, and they did not develop galvanization between themselves and the hulls. However. the mechanical qualities of polyamide, insufficiently high tensile strength (7 kg/mm^2)[1] and low modulus of elasticity (100-150 kg/mm^2)[2]. limited application.[3]

In the early sixties tests were conducted in Russian tugs which had four-blade polyethylene propellers with a diameter of lm (3.3 ft) and a weight of 14 kg (30.8 lbs). An equivalent bronze propeller would weigh 112 kg (247 lbs). The highly polished plastic surface made possible an efficient use of energy. The material was resistant to corrosion and could be counted on for prolonged life. Also. tests of polyethylene propellers with a diameter of 1.7m (5.6 ft) were conducted in seagoing ships.

A 1960 publication’ gives historical data on small nylon (polyamide) propellers, successfully used in Icelandic waters. Nylon propellers showed considerabley less cavitational erosion and corrosion than that experienced with metallic propellers. Further nylon propellers had better resistance to impacts with floating debris. Reportedly. a nylon propeller on a tug often used as an ice breaker outperformed bronze propellers. The singular disadvantage is the high cost of the required mold for different propeller designs.

It is known that metal propellers encapsulated with polyamide (nylon) or polyethylene have been tried to achieve greater corrosion resistance. surface smoothness and reduced galvanization. This technique yields the advantages of plastics while retaining the high structural properties of metals. However. the results were not traceable.

While polyamide and polyethylene were suitable for small propellers they are not for large propellers because of inadequate flexural modulus. However. fiber reinforced plastic propellers. up to 10-feet in diameter. have been successfully demonstrated.

Fiberglass propellers appeared in the United States in the forties. At the same time, development began in the USSR. By 1961 the Russians built fiberglass propellers by a compression process in heated forms and by contact and vacuum forming. They were used in fast boats, steamships and fishing vessels. Their diameters ranged between 330-3000 mm (1.1-9.8 ft). Test results demonstrate the feasibility of large epoxy propellers.

in 1961, Kaman Aircraft Corporation contracted with the U.S. Navy to build a four bladed 7-foot diameter epoxy fiberglass propeller. It had a metallic hub. For high structural efficiency bundles of fibers were aligned to anticipate stress fields. Final blade shape was obtained by cross laminating epoxy saturated cloth over the inner structure. The skin was sanded and coated with a polyurethane elastomer to overcome unevenness and minimize cavitation. The polyurethane coating was applied in two coats of different colors so that areas of high erosion could be identified.

The propeller was delivered to the Brooklyn Navy Yard for testing. Attempts to obtain the test conditions and results were not successful. Several sources advised that the propeller may have failed through delamination.

Within the last 15 years considerable improvements have been made in reinforcing fibers and resins. Further improvements have been made in fabrication techniques

[1] 15.400 psi
[2] 142.000 psi -203.000 psi
[3] From .“Applications of Plastics for Marine Outfitting and Marine Installation.. by M. Popovic of Yugoslavia. translated in 1973 for Wright-Patterson Air Force Base.
[4] “Nylon for ships Propellers” by A. Clark. PIastics. March 1960.

such as lay up methods. filament winding. and curing. High modulus fibers of polyamide (Kevlar) and/or graphite fibers can be used to obtain a flexural modulus greater than that obtainable with glass fiber. Or. such fibers can be used in conjunction with glass fibers to achieve intermediate stiffness.

3.1.2 *Related Experiences with Non-Metallic Propellers*

The high order of success now being obtained in large diameter plastic blades (helicopters, wind tunnels, water cooling towers, etc.) gave impetus to examining the possibility of developing less costly and lighter propellers for merchant ships. In searching for data which might assist in determining the technical feasibility of a large diameter ship propeller (greater than 15 feet), people in many areas of pertinent expertise were contacted. They represented:

Fiber Manufacturers
Filament Winding Companies
Manufacturers of Composites
Aerospace Equipment Manufacturers
Naval Architects
Massachusetts Institute of Technology
Maritime Administration
USCG
U.S. Navy

Large ***industrial*** propellers. up to 28 feet in diameter. have been fabricated from fiberglass and have been in service for over 20 years. They are used in water cooling towers, chemical plants, air conditioning towers. etc. In these applications, the blades are flexed up to 12 inches during each revolution. The fiberglass blades for these propellers are fabricated in a matched metal die. Typical characteristics are:

blade width . . . .18 to 20 inches
shank diameter . . . . .up to 8 inches
weight . . . .1501bs for a 12-foot blade
operating speed . . . ..178 to 350 rpm
Flexural modulus . ...4.5 x 10^6 psi

Presently. the Structurlite Company manufactures 12. 18, 22 and 28 ft. blades and is designing 32-foot blades. These are preferred over metal blades because of less weight. less corrosion, and less cost in large sizes. Tillotson-Pearson also manufactures the same type of fiberglass propeller. Kaman is now designing a 200 ft. diameter windmill which will use filament wound fiberglass. All three companies were optimistic about the possibility of fabricating a functional fiberglass large-ship propeller. All recommended that a scaled down model be fabricated for preliminary tests.

Further. in early 1977 the Energy Research and Development .Administration awarded a construction contract for a wind powered 1500 kilowatt generator which will utilize two filament wound fiberglass blades. each 100 feet long.

At Boeing's Vertol Division helicopter blades up to 40 feet in diameter are fabricated. Each consists of a 'Nomex' honeycomb core shaped to the desired contour. The core is faced with a preimpregnated woven glass/epoxy fainng layed up at 45°. The fairing is 3 inches x 10 inches x 13 feet and carries 90% of the load; working stress on the blades is 20.000 psi. Leading edges are faced with 25 to 50 roils of titanium to minimize erosion from rain and sand (In a recent crash landing one of these blades cut through a 15-inch diameter tree trunk and remained intact.). Vertol has also found that fiberglass blades electroplated with nickel have excellent resistance to erosion.

Sikorsky's experiences with composite rotor blades have been equally favorable to those of Vertol. Honeycomb structure was recommended for its good impact strength, low weight. and non-corrosion properties but was said to be high in material and shaping costs. Nomex. high density grade, 8 to 9 lbs/fi^3, was suggested for consideration.

3.1.3 ***Suggested Approaches to Lowering Propeller Costs***

Two approaches to lowering a propeller cost have been considered:

- ***Encapsulation of a Steel Propeller with Fiberglass***

Manufacturing costs for a 27-foot diameter propeller were not obtainable: however. the researchers estimates are contained in Table 3.1.

- ***Fabrication of a Plastic Propeller***

This approach hinges largely on fabrication of a propeller using a combination of plastics with fibers and possibly metal reinforcements.

Small diameter propellers can be made of homogeneous material such as nylon or polyolefin. This type of ship propeller has been reported in the literature to have functioned well in diameters less than 5 feet. The flexibility of these blades was found advantageous in resisting damage from debris laden harbors as well as in icy waters. How-

ever, as diameter increases and the loading increases. the need for greater rigidity rapidly increases. Hence consideration for a large diameter ship propeller of plastic must take into consideration means of obtaining a flexural strength higher than that obtainable with a homogeneous plastic. For example. from Table 3.2 it can be noted polyester or epoxy resins per se do not have the required strength properties. However. the monolithic reinforcing materials shown in the table have high strength properties. particularly tensile strength.

When these high modulus fibers are made into a resin/ fiber composite strength properties fall between those for the resin and fiber (Table 3.3). A unidirectional glass/epoxy composite has a transverse tensile strength as high as 160.000 psi but its fiexural modulus is only about 3 million psi. A filament wound glass/epoxy composite offers tensile strength from 50.000 to 250.000 psi and a flexural modulus of 5 to 7 million psi.

TABLE 3.1 ***Estimated Costs to Encapsulate a Steel Propeller with Fiberglass (Late 1976)***

Item	Nickel/ Aluminum/ Bronze (a)	steel/ Fiberglass (b)	Savings
Raw Material	$99,000 (a)	$ 27,500 (b)	(+) $71,500
Grinding of Casting	80,000 (c)	5,000 (d)	(+) 75,000
Fiberglass Encapsulating	—	50,000 (e)	(–) 50,000
Neoprene Coating (f)	—	6,000	(–) 6,000
Pattern Tooling, Casting, Profit	71,000 (c)	71,000 (c)	—
Total	$250,000	$153,750	$90,500

(a) 90¢/lb (Nickel/Aluminum/Bronze)
(b) 25¢/lb (Steel)
(c) Approximations by researcher.
(d) Only nominal grinding is required since the fiberglass would be molded to nearly designed contour.
(e) Estimate by Structurlite Co.
(f) To minimize cavitation.

TABLE 3.2 ***Properties of Materials of Construction***

Material	Tensile ($\times 10^3$ psi)	Elong. (%)	Young's Modulus*	Density Lbs/In^3	$/Lb
Glass (E)	350	4	10	0.093	0.50
Polyaramid (Kevlar 49)	430	2	19	0.053	8-9
Graphite	360	1	34	0.063	25
Polyester Resin	6-13	5	3-6	0.05	0.48
Epoxy Resin	4-13	3-6	3-4	0.05	0.67
Nickel/Aluminum/ Bronze	74	12	18	0.300	0.90

*($\times 10^6$psi)

Kevlar 49, a polyaramid fiber with epoxy resin, has adequate tensile properties but again is low in flexural modulus compared to that for a nickel/aluminum/bronze alloy. Unidirectional graphite fiber with epoxy when measured in the transverse direction can give adequate tensile strength for the high stress areas. This is said by many different authorities to be quite feasible. However. cost could be prohibitive if a high quantity of graphite fiber were required to achieve the required stiffness or high modulus. Therefore, a very detailed analysis of stresses for critical areas would have to be developed so that the costlier materials would be used only where needed and in the smallest amount necessary.

The required stiffening could be satisfied in large part by the fiber direction. Also. metallic spars could be embedded in the blades to add rigidity.

Thus. the design of the blade's structure using resin. high modulus fibers. metal ribbing. a high density foam core. an optimum fabrication method for strength. and skin coating to minimize cavitation is said by all experts to be no small task to accomplish. But nevertheless they believe that it justifies serious exploration at this time. Without exception. all recommended the building of a scale model to produce engineering data required to design a prototype. It was unanimously stated that the blades should be individu. ally manufactured for insertion into a metallic hub. Therefore. four different approaches utilizing metal hubs were cost estimated as presented in Table 3.4.

In two construction types there would not be any savings while in Approaches#3 and#4, cost savings are estimated at 29% and 36%. Further. all approaches indicate. as a minimum. 55% reduction in weight. In addition to reducing the propeller handling problem during installation. there would be significant savings available through redesign of the sterntube bearing.

It is stressed that the estimates are rough approximations as to material amounts as well as to costs to perform each manufacturing operation.

While the technical feasibility of a composite propeller cannot be confirmed at this time. without exception the

[6] **Authorities in propeller** design. fiber manufacutre. filament winding and in manufacturing fiberglass composites as in aerospace components

TABLE 3.3 ***Properties of Composites***

Fiber	Fiber Direc-tion	Resin	How Fabri-Cated	Tensile ($x10^3$psi)	Elong. (%)	Flexural Modulus ($x10^6$psi)	Density Lbs/In^3	$/LB Fiber	$/LB Pre-Preg
Glass (Woven Roving)		Poly-ester	Molded	30-55	2	1.5	0.06	0.50	0.65
Glass	0°			51	2	2.7	0.06		
Glass	0°	Epoxy	Molded	160	5.7	3	0.07		6.00
Glass	Varied	Epoxy	Filament Wound	50-250	1.5-2.8	5-7	0.07		
Kevlar 49	0°	Epoxy	Molded	90-200	1.8	7-11	0.06	8.50	12
Kevlar 49	90°			4		0.8	0.06		
Kevlar 49	Woven	Polyester	Molded	55		2	0.06		15-20
Kevlar 49	"	Epoxy		65		4	0.06		
Graphite	0°	Epoxy	Molded	180	1-2	19-33	0.06	30-50	42-70
Graphite	90°			6	1-2	1	0.06		
Graphite	0°/90°			70	1-2	7	0.06		
Nickel/ Aluminum/ Bronze				74	12	18	0.30		

numerous authorities contacted were optimistic.[6] The general concern was being able to design enough flexural modulus into the plastic blade. Cavitation effects would have to be determined. There is the possibility that the ability to flex may be a way to reduce vibration caused by cavitation at the blade tips. Then, as in helicopters, flexing blades would be designed to assume a desired position at designed speed.

Considering the potential saving of up to $90,000 per propeller, a $20.000 level of effort for initial design to determine technical feasibility is recommended.

3.2 *Hatch Covers*

Fiberglass hatch covers have been in use for seven years; over 1500 inland barges are so equipped. Approximately 600 sets have been installed in LASH barges. But. both inland and LASH barges are not required to be USCG inspected.

Fiberglass hatch covers as manufactured by Preform have been as large as 44 feet long and 27 feet wide weighing 3 tons. Equivalent steel covers weigh 300% greater. Since 1969 approximately 38 million pounds of fiberglass have been used for hatch covers. The life expectancy is 12-20 years for steel with at least 20 years being predicted for fiberglass. Where corrosive chemicals are carried. the fiberglass will outlast steel.

The cost of fiberglass hatch covers is estimated to be 5-20% less than that for steel.

Fiberglass hatch covers produced by another manufacturer, which have failed in service are believed to have incorporated poor design features. This is not surprising: shipbuilders also had to acquaint themselves with new design details when they shifted from riveted to welded ships.

Preform obtained ABS approval for two-section 20 feet by 60 feet fiberglass hatch covers in ocean ***going unmanned*** barges. To do this Preform had to prove strength and stiffness equivalent to steel.[7] However. fiberglass hatches for unmanned barges over 4,000 gross tons would be required to meet the USCG structural fire protection requirements.[8] There are no known cost effective plastics which would suffice.

3.3 *Electrical Junction Boxes*

Currently electrical junction boxes for marine use are made from brass. As many as 105 brass junction boxes in six different sizes are used in a typical merchant ship. These boxes weigh from about 2 to 6 lbs each. One shipbuilder said that quotations for fiberglass junction boxes were more expensive than for brass. Yet, the basic fiberglass material is less costly and has less price fluctuations:

	Brass ¢/lb	*Fiberglass ¢/lb*
1974	83	43
1975	58	42
1976	68	43
1980	82	52

[6] **A contributing factor is the prediction that** energy considerations will create a demand for "big slow speed lightly loaded propellers..' See "A Naval Architect's View of the Future of Ocean Transportation.. by Charles Zeien. SNAME Philadelphia Section. 19 March 1976.
[7] Section 18.7.6 of the ABS Rules for Building and Classing Steel Vessels. 1977.
[8] 46 CFR 9207-1.-5.

TABLE 3.4 Cost ***Estimates*** *to Construct a Composite Propeller*

Approach	Design	Part	Material	Material: LBS X000	Material: $/ LBS	Material: Dollars X000	Labor ($X000): Pattern	Labor ($X000): Casting	Labor ($X000): Grind Match	Labor ($X000): Fabricate	Labor ($X000): Coat	Mfg. Cost (70%) $X000	G&A (30%) $X000	Selling Price $X000
Conventional	Single Casting	Propeller	Nickel/ Alum./ Bronze	110	0.90	89	6	10	60	-	-	175	75	250
#1	Composite	Hub	Nickel/ Alum./ Bronze	27.5	0.90	24.75	2	3	15	-	-			
		Blade	Graphite Epoxy (Skin)	0.88	70.00	61.60								
			FRP Tape (Skin)	2.64	3.00	7.92	5	-	5	40	6	184	79	263
			Glass Rovings (Core)	14.08	0.50	7.04								
#2	Composite	Hub	Steel	27.5	0.25	6.88	2	3	15	-	5(a)			
		Blade	Graphite Epoxy (Skin)	0.88	70.00	61.60								
			FRP Tape (Skin)	2.64	3.00	7.92	5	-	5	40	6	171	74	245
			Glass Rovings (Core)	14.08	0.50	7.04								
#3	Composite	Hub	Nickel/ Alum./ Bronze	27.5	0.90	24.75	2	3	15	-				
		Blade	Steel Spar Insert	5.0	0.25	1.25	-	-	5			124	53	177
			Glass Cloth/ Epoxy(b)	3.32	3.00	9.96	5	-	5	40	6			
			Glass Roving(c)	13.28	0.50	6.63								
#4	Composite	Hub	Steel	27.5	0.25	6.88	2	3	15	-	5(a)			
		Blade	Steel Spar Insert	5.0	0.25	1.25	-	-	5					
			Glass Cloth Epoxy(b)	3.32	3.00	9.96	5	-	5	40	6	111	48	159
			Glass Roving(c)	13.28	0.50	6.64								

(a) Encapsulate Hub with Fiberglass
(b) Skin
(c) Core

Until a standardization of the six different size junction boxes can be made. the price of a plastic junction box will be high because of the low unit volume over which the metal mold must be amortized. As the volume usage for a given size increases. it is expected that the plastic junction box would become less costly than brass. Normally about 5.000 units are required to justify mold costs. Fire retardant plastics should be specified.

3.4 *Electric Cable Insulation, Jackets and Transit Devices*

No cost savings are evident from alternative materials because of the low cost insulation and jacketing now used.

Regarding the USCG requirement[9] that insulation and jacket materials used for splices must be "chemically compatible with each other and with the materials of the cable." the only polymer known to have a trouble potential is polyvinyl chloride (PVC). If formulated with a ***liquid*** plasticizer. the plasticizer could migrate into other materials. However, ***polymeric*** plasticizers are well known for their nonmigratory properties and are often used to plasticize PVC. Raychem Corporation advised that the adhesive coating on its cross-linked polyethelyne splice material is specifically formulated to chemically combine with most liquid plasticizers used in PVC in order to prevent plasticizer migration.

Multi-cable transit devices which use pourable epoxy resins as the sealant have been ABS accepted on a case basis for several years. Their use is limited because epoxy cannot withstand the USCG requirement for a 1700°F fire test of one hour while not contributing to the fire.

Recent research produced a transit seal method with cheaper. water mix. refractory cements which withstand the fire test and have USCG acceptance. [10] The ABS Rules have been modified[11] as a result of this research to acknowledge such pourable materials. Also. the refractory cements are classified as ratproof by the Public Health Service. [12] Because the pourable refractory cements maybe used for every transit requirement. i.e., watertight. fire-tight. smoke-tight and ratproof. the planning and installation of such seals are extremely simplified as compared to the discretion which must be used to limit epoxy to only certain locations. Thus. the use of epoxy for bulkhead and deck transits is not recommended.

3.5 ***Propulsion Shafting and Fairings***

High-modulus plastic composites might someday be suitable for propulsion shafting in ships. In addition to special aerospace applications advanced composites using boron or carbon fibers are being used in sports equipment such as golf clubs and fishing rods. Similar composites were found to be ideal for helicopter drive shafts and there is already one such application in an English Channel hydrofoil ferry.

High modulus fibers are expensive. ranging from $25 to $100 per pound. Because of their high strength to weight ratios, composites reinforced with such fibers are being studied for truck and automobile driveshafts. Considering an annual production of 2 1/2 million trucks and 10 million automobiles, a composite manufacturer estimates that graphite fiber costs could drop to less than $10 per pound within five years of such usage.

Further the same source advised that expensive fibers. such as graphite, would be longitudinally oriented for bending and that cheap fiberglass would be wound circumferentially for torsional loads. Thus, on a weight basis. finished steel drive shafts which cost $1.10 per pound could be replaced in the future by lighter graphite/glass fiber composites at an estimated $5 per pound.

By varying quantities and types of fibers and by winding or aligning them in prescribed patterns. strength properties of a composite can be controlled in magnitude and directed in specific orientations. Thus. much development would be required for composite shafting in ships. Among these would be the treatment of compressive loads and coupling design. But until manufacturers of high-modulus fibers are able to significantly lower prices. consideration of this application should be deferred.

Fiberglass has been used successfully to wrap steel shafting exposed to seawater for about fifteen years. Its substitution for earlier coating types improved productivity and at the same time provided superior protection against corrosion.

[9] 46 CFR 111.60 - 40(c)
[10] USCG letter (G.MMT.Y82) 9620/2-I dated 3 September 1975 re Todd Seattle drawings 496-SK-002 through 005 for the National Shipbuilding Research Program.
[11] ABS Rules for Building and Classing Steel Vessels. 1977.35.139.2d. P. 35-48.
[12] PHS, F&DA letter by James F. Beddow dated 11 July 1974.

Fiberglass shaft fairings have been tried in both commercial and naval ships. An account[13] of Navy experiences describes poor success due to the failure of mechanical fasteners. In commercial ships. probably due to larger shaft diameters and slower operating speeds. there are such installations which appear to be satisfactory.

[13]NAVSEC Report 6136-75-162 dated December 1975.

4.0 CURRENT AND HISTORICAL APPLICATIONS

4.1 Findings from Literature Review

Prior to 1960 marine usage of plastics, including boat hulls, was relatively limited if only total weight is considered. However, the number of applications in many different ship types was significant. The largest usage was in passenger and naval vessels. The British pioneered applications in ocean going ships.

A compilation of noteworthy marine applications up to 1960 is found in Table 4.1. Of these only two were found unsatisfactory, namely glazing which scratched excessively and wash basins which lost their finishes due to the use of abrasives or improper cleansing agents. There are now specially coated acrylic (Lucite, Plexiglass) or polycarbonate (Lexan) glazings which are successfully used, as in railroad cars, because they have much greater scratch resistance than the earlier materials. Also, there are now upgraded plastics that are commonly used for wash basins. These are successful as long as proper cleansing instructions are followed.

Vent systems made from plastic duct have been evaluated by the Navy.[1] While corrosion, weight and noise considerations led to the use of fiberglass and PVC, such systems were found to be mere expensive. Further, lower stiffness required more support. Vent systems using plastic duct are still more expensive and are used primarily in corrosive locations.

Other marine uses for plastics noted since 1960 are summarized in Table 4.2. An example of long term service life for a fiberglass product in severe marine use is shown in Table 4.3.

4.2 Findings from Field Contacts

Numerous naval architects. subcontractors, and shipbuilders were interviewed for assessing plastics in specific applications.

4.2.1 U.S. Shipyards

Plastics applications encountered in 11 U.S. shipyards are summarized in Table 4.4. Those found to be most commonly applied are:

Joiner Bulkheads	Melamine/Marinite
Flooring	Vinyl/Asbestos
Shower Stalls	Melamine/Marinite
Light Diffusers	Acrylic
Mattresses	Polyurethane
Chairs	Naugahyde
Dresser Tops	Melamine
Table Tops	Melmaine
Desk Tops	Melamine
Curtains	Nylon
Life Boats	Fiberglass
Insulation	Polyurethane Foam
Rugs	Nylon, Acrylic

All are well established in merchant ships[2] with little change occurring with the exception of joiner bulkheads and stall showers.

4.2.2 *Japanese Shipyards*[3]

The information in Table 4.5 and the following are based on inquiries in six shipyards in Japan:

Bulkheads	Decorative surface, for living quarters may be melamine laminate, polyester laminate, vinyl sheet, or simply paint depending upon the owner's specification. The substrate for the decorative finish may vary from asbestos board, plywood, to particleboard.
Ceilings	Usually the same as used for bulkheads.
Flooring (Covering)	Vinyl or Vinyl/Asbestos
Window Frames	Fiberglass is commonly used for port shrouds.
Baths/Showers	All six Japanese shipyards have installed fiberglass units.
PVC Piping	Two of the six shipyards visited used PVC for fresh and chilled water supply. PVC is being used more for drain, waste and vent systems.
Hatch Covers	Up to 500mm in fiberglass.

[1] **Plastics."' March 1960. pp** 93-95.
[2] **A Coast Guard authority commented that because there are different regulations for different ship types, prudent selections to match the materials and applications are required and "more often than not the uses indicated would be permissible ..' For example. the Passenger Vessels Regulations require that "rugs and carpets in stairways or corridors shall be of wool. or other materials having equivalent fire-resistive qualities."' See 46 CFR 72.05- 1O(o)**
[3] **This project did not require visits to foreign shipbuilders. The material reported is based upon a fortuitous opportunity.**

TABLE 4. 1 ***Plastics Usuge in Ships lip to 1960***

General Use Area/Application	Plastic used	Ship	Reported Comments	Serviceability Excel-lent	Serviceability Satis-factory	Serviceability Poor
LIVING QUARTERS						
Bath Tub	Fiberglass	Cunnard Passenger	Excellent after 7 years	X		
Shower/Toilet	Fiberglass	Oanberra	Complete Exposure	X		
Table Tops	Melamine	Thames Field		X		
Tops for Dining Area	Melamine	Oronway		X		
Tile Floors	Pvc	Tanker	Cigarette Marring Wear Good		X	
Light Fixtures	Acrylic	Reina Del Mar	Good		X	
Window (Glazing)	Acrylic		Scratched after 2 yrs.			X
Port Hole Box	Pvc	Passenger	Exc. after 3 yrs.	X		
Wash Basins	Fiberglass	Naval	Poor after 3 yrs.			X
PVC Finished Bulkhead	Pvc	Passenger	Low Cost less durable than Formica		X	
Wash Basins	ass	Naval	Surface Abrasion from Cleaners			X
PIPING						
Waste/Sanitation Piping	Fiberglass		Better than copper	X		
Waste/Sanitation Piping	PVC	Cunard	Excellent after 7 years	X		
Washdown Piping (above deck)	PVC	Naval	For radioactive fall out	X		
Cargo Line	Glass/epoxy	Hemisings	Shell Tanker	X		
PROPULSION						
Propeller	Nylon	Danish Tugs	15" to 6 ft. Dia.		X	
Propeller	Nylon	30 ft. Utility boat	4 ft. Diameter		X	
Propeller	Fiberglass	Russian	10 ft. Diameter	?	?	?
Wrapping for Prop Shaft	Glass/Epoxy	Canberra: others	Eliminated corrosion	X		
MISC.						
Lifeboats	Fiberglass	Canberra	Accommodations for 3326 persons	X		
Wheel House	Fiberglass	USS Sutherland	Excellent after 2 years	X		
Wheel House	Fiberglass	Brave		X		
Swim. Pool	Fiberglass	BP Tanker		X		
Swim. Pool	Fiberglass	Empress of Britain	Passenger Ship	X		
Permanent Awnings	Glass/Epoxy	Irish Hawthorne	Eliminated Maintenance			
Sonar Dome	Stael/Plastic Skin	Nautilus		X		
Insulated Hatches	Polyurethane foam	Oriana	50 tons of foam used	X		
Food Provision mom	Polyurethane foam	Garonnit	37,000 Ton Tanker	X		
Lining for Storage Hold	PVC/Plywood	Camito				

TABLE 4.2 ***Marine Plastic Uses After 1960***

General Use Area/Abdication	Plastic Used	ship	Comments	Serviceability: Ex-cel-lent	satis-fact-ory	Poor
OUTFITTING						
Wheel House (Dredger)	Fiberglass	Acrow	Lower Cost Than Steel	X		
Port Light Boxes	Fiberglass	General		X		
Ship Funnel Cowl	Fiberglass		20.5' X 12.5'	X		
Ventilation Inlets	Acrylic	General	Used above Deck		X	
Hatch Covers	Fiberglass					
Insulation	Polyurethane Foam	LNG	Insulator	X		
Elec. Power Equip.	Phenolic	General	Housings: Components		X	
Elec. Power Equip.	Aabestos/Phenolic	General	Housings: Components	X		
Elec. Power Equip.	Melamine/Phenolic	Genaral	Housings: Components	X		
Electrical Conduit	Pvc	Queen Eliz. II	61 Miles PVC Conduit	X		
Showera & Bath	Acrylic	Queen Eliz. II	300 Acrylic Bath Tubs	X		
Chairs (Upholstery)	Pvc	Queen Eliz. II		X		
Chair Padding	Polyurethane Foam	General		X		
On Deck Furniture	Fiberglass	Caronia	Passenger Ship		X	
Modular Bathrooms	Fiberglass	Chevron Tankers	Not yet eval.			
Rope	Nylon, Polyester	General	Also Polypropylene	X		
Ballast Pipe	Fiberglass	Chevron Tankers	Not yet eval.			
Ship Bearings	Saveral	General			X	
Rudder Voids	Polyurethane Foam	General		X		
Covered Bulkhead	Pvc	Chevron Tankers	Gypsum Replaced Marinite		X	
PROPULSION						
7 BLADE Propeller :30" Dia.)	Glaas/ 'Polypropylene Foam	Hovercraft	2200 RPM; 130 lb. Thrust	x		
SUBMERSIBLES						
Deep Diving Capsules	Fiberglass	Naval R&D				
Submarine Rudder	See (a)	Navy	8' x 2' x 10"	X		
Mast Fairings	Fiberglass	Nuclear Sub		X		
BARGES						
Lash Barge Hull	See (b)	Pacific Far East Line	131 built: 69 Cancelled (c)		x	
SAFFTY						
Helmets	Fiberglass	General		X		
Welding Clothing	Nomex	General	Non-Burning	X		

(a) Fiberglass Skin/Steel Spar/Foam.
(b) Double Walled Honeycomb Construction - Fiberglass.
(c) Non-Conforming with Spec (43% Lighter than Steel).

TABLE 4.3 ***Properties of Glass Reinforced Plastic Laminate Fairwater in USS HALFBEAK***

	Condition	Original (a) Data	Data After 11 Yr. Service Panel 1	Panel 2	Specification Av. Requirement (b)	
Flexural strength, psi	Dry	52400	51900	51900	51900	50000
	Wet (c)	54300	46400	47300	46900	45000
Flexural modulus, psi x 10^6	Dry	2.54	2.62	2.41	2.52	2.50
	Wet	2.49	2.45	2.28	2.37	2.30
Compressive strength, psi	Dry		40200	38000	39100	33000
	Wet		35900	35200	35600	28000
Barcol hardness	Dry	55	53	50	52	
Specific gravity	Dry	1.68	1.69	1.66	1.68	
Resin content, %	Dry	47.6	47.4	48.2	47.8	35-43

(a) Average of 3 panels. (b) Mil-P-17549 (c) 2-hr boil.

Source - Lubin, G., "Handbook of Fiberglass and Advanced Plastic Composites," (New York: Reinhold Book Corporation, 1969), page 761.

TABLE 4.4 *Principal Plastics Usage Noted During Visits In U.S. Shipyards*

Gan'l Use Area/ Application	Materials used	U.S. Shipyards Using Plastics for Indicated Application: Avon-dale	Bath Iron	Bath-lehem	FMC	GD	Harbor Boat	Ingalls	Kelso	Nat'1	Newport News	Sun ship
LIVING RTE												
Bulkhead	Melamine/ Marinite	X	X	X				X	X	X	X	X
	Vinyl/Sheet Matal/ Gypsum					X						
	Al/Gypsum/ Al/Melamine				X					X		
	Vinyl Merinite				X						X	
flooring	Vinyl/ Asbestos	X		X		X		X		X		
	Vinyl					X						
Base Board	Vinyl			X						X		X
Shower	Fiberglass	X			X			X			X	
	Melamine/ Marinite (a)		X	X					X	X		X
	Ceramic	X										
	Stainless Steel	X										
	Steel					X			X			
Drain/Waste	Vinyl (PVC)	X	X	X					X		X	X
	Metallic	X		X	X	X		X	X	X	X	X
Ballast or	Fiberglass			X	X							
Cargo	Metal	X	X	X	X	X	X	X	X	X	X	X
MACHINERY												
Chocking	EPOXY Chocks	X		X		X				X		

(a) Stainless steel wings are attached to walls to complete stall shower.

TABLE 4.5. ***Plastics Usage Noted in Japanese Shipyards***

Gen'l Use Area/ Application	Materials Used	Japanese Shipyards Using Plastics for Indicated Application					
		Hitachi Sakai city	Kawasaki Kobe	Mitsubishi Kobe	Mitsubishi Yokohama	Mitsui Chiba	IHI Yokohama
LIVING QUARTERS							
Bulkhead	Melamine/ Asbestos/ Melamine	X	X	X		X	X
	Melamine/ Plywood/ Melamine						X
	Polyester/ Asbestos/ Polyester				x		
	Polyester/ Plywood Polyester	X				X	X
	Vinyl/ Plywood/ Vinyl				x		
	Paint/ Plywood/ Particle-board				X		
Ceilings	As above	Ceiling material same as Bulkhead (a)					
Flooring	Vinyl/ Asbestos	X	X			X	
	Vinyl		X	X	X		X
Window	Fiberglass	X	X		X	X	X
Frames	Aluminum			x			x
	Painted					x	
Baths (Conventional)	Melamine/ Asbestos/ Melamine		X (b)				
	Fiberglass	x (c)		X (d)			
	Tile/Steel			X (e)			
Baths (Modular)	Fiberglass	2 pcs (f)	2-3/Ship	Studying	(g)	1/Ship (h)	(i)
Doors (Exterior)	Polyester/ Plywood/ Polyester			X			
	Paint/Hollow steel					x	
	Fibarglass/ Hollow Steel					X	
Doors (Inside)	Fibre glass/ Plywood/ Fiberglass		X		X	X	
	Polyester/ Plywood	X					
	Melamine/ Plywood/ Melamine				X		
Doors (Corridor) (j)	Fiberglass/ steel Fiberglass		X				
	Fiberglasss Plywood/ Fiberglass	X		X			
	Steel/Paint				X		

TABLE *4.5* ***Plastics Usage Noted in Japanese Shipyards (continued)***

Gen'l Use Area/ Application		Materials Used	Japanese Shipyards Using Plastics for Indicated Application: Hitachi Sakai City	Kawasaki Kobe	Mitsubishi Kobe	Mitsubishi Yokohama	Mitsui Chiba	IHI Yokohama
PIPING								
Fresh	(cold)	PVC	X	X		X	X	X
		Copper						X
		Steel						
	(hot)	Steel			X	X		X
		Copper	X	X	X	X	X	X
Sani-tary	(flush)	Steel		X	X (k)	X		X
		PVC	X				X	
		Copper					X	
	(Drain)	Steel	X	X	X	X		
		PVC	X (l)	X				X
MACHINERY								
Chocking		Steel	X	X	X	X	X	X
ELECTRICAL								
Conduit for Wires		Steel	X		X			X
		Plastic	X			PVC (m)	PVC	
HEAT-AIR CONDITIONING								
Fixture Inlets to Rooms		Steel		X				
		Fiberglass	X	X		X		X
CARGO								
Hatch Covers		Steel		X				
		Fiberglass	X (n)	X				
SAFETY								
Life Boats		Wood			X			
		Fiberglass	X	X	X			

(a) Kawasaki (Kobe) uses painted plywood for ceilings
(b) 40 showers on 1 ship
(c) Tubs
(d) 20 tubs on 1 ship
(e) 20 showers on 1 ship
(f) 6 yrs. of satisfactory service
(g) 3 yrs. of satisfactory service
(h) Found costly
(i) 12 units/ship
(j) Door from bridge to corridor
(k) PVC pipe sags
(l) Increasing
(m) Rectangular
(n) 200 covers/ship (500 mm)

An IHI[4] listing of the plastics used in a 200,000 DWT VLCC is contained in Table 4.6. As can be noted. the construction material varied widely depending upon the owner's specifications which reflect the requirements of different registries.

TABLE 4.6 ***Plastics in VLCCs***

Purpose	Kind of Material	Japanese Ship	Other Foreign Ship
Rudder bearing bushing	Phenol resin	100 kg	100 kg
Fresh water pipe Sea water pipe in living quarters Potable water pipe Scupper pipe	PVC pipe (including fittings)	2.2 tons	2.2 tons
Flooring tile (cabin, passage)	PVC/Asbestos	600 m^2	1,300 m^2
Deck composition (weather deck)	Synthetic rubber (Neoprene)	200 m^2	750 m^2
Deck composition (in accommodation space)	Synthetic rubber	1,870 m^2	1,900 m^2
Overlay of wall surface	Laminated hard plastic, PVC, cloth	4,000 m^2	11,000 m^2
	Melamine	—	1,700 m^2
Door of sanitary space	FRP/Ply/FRP	15	5
Skirting plate of cabin wall	PVC (Recessed)	—	700 m
Handrail, Stormrail	PVC/Steel	—	0.5t
Reefer door	FRP with urethane for heat insulation	4 sets	4 sets
Reefer insulation	Foam urethane	1t	1.3 t
Cover for insulation	Canvas with polyester overlay over glass wool	750 m^2	400 m^2
Chair	Vinyl covered, with polyurethane stuffing	135	120
Sofa	Vinyl covered, with polyurethane stuffing	55	45
Mattress	Cotton cloth urethane stuffing	55	45
Desk, table	Laminated hard plastic top (Melamine)	60	55
Lifeboat	FRP	—	2
Life raft	FRP	—	2
Awning (bridge, swimming pool)	Corrugated FRP	230 m^2	—
Valve lining (corrosion resistant)	Polyester	abt 100	—
Paste, filler	Various kinds	abt. 3 t	abt. 3t
Paint	Vinyl	10 t	—
	Tar-epoxy	75 t	180 t
	Epoxy	1 t	80 t
Electric wire	Synthetic rubber & vinyl	abt. 100,000 m	abt. 80,000 m
Compound (for insulation & stuffing)	Silicone & epoxy	abt. 100 kg	abt. 100 kg
Bathroom - modules		2 units	20-25 units FRP 17-22 shower FRP

[4]Ishikawajima - Harima Heavy Industries Co.. Ltd.

5.0 *FACTORS FOR USING PLASTICS*

5.1 *General*

Plastics usage is distributed over 18 commodity or large volume plastics, each generically different, and at least 20 specialty engineering types, again generically different. There are two main classes: thermoplastic and thermosetting.

A thermoplastic polymer is a plastic that under the conditions of applied heat and/or pressure can be formed or molded into a shape. This plastic type can be repeatedly granulated, heated, and remolded. Thermoplastics constitute 80% of all plastics used.

Thermosetting polymers become permanently rigid when heated or cured and cannot be reshaped or recycled. A thermosetting polymer is cured, or polymerized, by the addition of heat and/or a catalyst to the basic materials.

The breakdown of plastics usages by generic type is contained in Table 5.1 which shows that 89% of the total plastic business resides in seven generic classes. This reflects that over 30 generic classes share the remaining 11% of the market.

TABLE 5.1
Usages and Prices of Plastics

Type of Plastic	General Class	Billion (1976)	¢/Lb (Average)
Thermoplastic	Polyethylene	8.89	30-35
Thermoplastic	Polystyrene & its copolymers	5.03	26-57
Thermoplastic	Polyvinyl Chloride & its copolymers	4.63	24-42
Thermoplastic	Polypropylene	2.59	26-28
Thermoset	Polyurethane	1.62	45-55
Thermoset	Phenolic	1.32	45
Thermoset	Urea & Melamine	1.00	45
Thermoplastic/ Thermoset	Polyester	0.95	48-125
Thermoset	Alkyd	0.73	49-60
Thermoplastic	Acrylic	0.49	57
Thermoset	Epoxy	0.24	76
Thermoplastic	Nylon	0.21	108
	Others (greater than 20 generic types)	1.68	—
		29.38	—

"Source: *Modern Plastics,* January 1977.

Plastics because of their inherent nature. can be molecularly modified and/or formulated through additives. These modifications can alter not only physical properties but also fabricating characteristics. Common additives used in plastics include anti oxidants, plasticizers. lubricants. flow promoters, flame retardants, fillers, impact modifiers. antistatic agents etc. Plastics are often reinforced with fillers and fibers such as glass. carbon. and boron. Thus, it becomes readily apparent that there exists an almost infinite number of possible formulations for any specific use.

The multiplicity of different polymer grades for a given generic plastic are noted in Table 5.2. Some grades are purchased for their specific polymer properties while in other cases the particular grade may be bought for its fabricating characteristics.

TABLE 5.2 ***Typical Grades for Several Generic Plastics Classes***

Generic Polymer	No. of Grades Sold by Just One Principal Supplier of the Given Polymer	Principal Supplier for the Polymer Type Shown
Polyethylene (high density)	55	Phillips
Polypropylene	52	Exxon
Polyethylene (low density)	35	Union Carbide
Acrylonitrile/ butadiene/styrene	33	Uniroyal
Polystyrene	31	ARCO

Specific properties cannot be simply stated for a generic polymer class which may consist of up to 55 grades within the class. For other materials such as metal, wood, glass. etc., there are far fewer grades so that specifications can be more readily prepared.

Properties of the more commonly used polymers are tabulated in Appendix A. To stay within the scope of this study. properties for the numerous grades within a generic class of commodity plastics are expressed in terms of encompassing ranges. Even for the engineering or high performance plastics there are several grades for each generic type and these have different properties: again a range of properties is shown.

5.2 Polymers Which are the More Viable Candidates for Shipbuilding

No organic plastics can be classified as "incombustible" as defined by the USCG.[1] However, there are numerous grades of different generic plastics which are rated by Underwriters Laboratories (UL) as "Self-Extinguishing V-O." This means that a vertically positioned test specimen extinguishes itself within 5 seconds after a Bunsen burner is removed and the plastic does not release any flaming drops that ignite cotton placed directly beneath.[2]

Approximately 9.3 billion pounds per year of specifically formulated plastics, having various degrees of flame resistance, are used in buildings, heavy construction appliances, electrical/electronics equipment, and transportation vehicles. All these are governed by various flammability codes. It is of interest to note that one wide-body aircraft has 10,000 sq. ft. of structural plastic composites. much of which is Nomex. Tests and codes are given in Appendix E. The shipbuilding industry has already obtained USCG approvals for specific applications. Two outstanding examples are fiberglass piping for ballast systems and fiberglass bathroom units.

Special grades of the following generic classes of plastics have been formulated to achieve a UL rating of "Self Extinguishing V-O:"

polystyrene
polypropylene
acrylonitrile/butadiene/styrene
polyvinyl chloride
phenolic
urea
melamine
acrylics
epoxy
nylon
aromatic polyamide (Nomex)
polycarbonate
polysulfone
polyphenylene oxide (modified)
polyamide/imide
polyester
polyarylsulfone
aromatic polyester copolymers
polyimide
polyphenylene sulfide
polyether sulfone
polytetrafluoroethylene
polyflorinated ethylene propylene
polychlorotrifluorethylene
poly (ethylene-polytetrafluoroethylene)
poly (ethylene-chlorotrifluoroethylene)
perfluoroalkoxy
polyvinylidene fluoride

The companies from which these plastics may be obtained are listed in Appendix A.

There are a host of self-extinguishing plastics which individually offer one or more outstanding and often unique properties as listed below:

design freedom
low density
resistance to seawater
resistance to chemical cargo products
resistance to wear on bearing surfaces
self-lubricating for bearings, bushings, cams. etc.
electrical insulators for conductors, tool and motor housings, connection boxes, etc.
resistance to low temperatures (cryogenic)
resistance to high temperatures (500°F.)
impact strength

However, there are some properties, particularly when compared to steel, where plastics cannot compete:

- incombustibility
- Young's modulus (high modulus plastic/boron fiber composites can compete in Young's modulus but these are costly)
- high and low service temperatures

In summation, plastics offer unique combinations of properties often not obtainable in other materials. Plastics have replaced steel, aluminum, brass, etc., in numerous applications (e.g., business machine housings, automotive front ends, etc.). So, the properties of plastics with proper design can be made functional for many metallic applications. Plastics because they are organic in nature will burn when held in a flame source. However, as already stated numerous plastics are classified as self-extinguishing and comply with safety flammability standards by numerous federal, state. and local government agencies. Some industries, such as for appliances, electrical equipment, etc., have set their own standards while others comply with standards set by such organizations as the American Society for Testing and Materials (ASTM), Underwriters Laboratories (UL), etc.

[1] 46 CFR 164.009
[2] UL Subject 94

5 .3 Materials costs and Avalilability

Factors which dominate material costs include:

- energy costs
- future availability of materials
- trends in metals and plastics prices

5.3.1 ***Energy Costs***

The amounts of energy required to produce a given quantity and volume of material have been summarized in Table 5.3. On a volume basis these data show copper to be the most energy intensive with aluminum second and steel third. Plastics require a relatively lower amount of energy for a given volume of material. The selling prices for these materials both on a weight and volume basis are given in Table 5.4.

From a material consideration alone. it is noted that the nickel/aluminum/bronze alloy used for propellers is expensive and with the composition being 78% copper, the price will remain high due to the energy required to produce copper.

Energy requirements for plastics on a volume basis. are only 15% of that for copper. But because mechanical properties are different energy considerations based on volume or weight are only meaningful in the context of specific applications. Should the increased cost of energy become a larger portion of the product cost, then plastics' costs should become even more favorable than those for metals.

TABLE 5.3 ***Relative Energy Requirenlents 10 Produce Various Materials***

Material	Specific Gravity	Lbs/Ft³	Primary Energy Consumption (Millions) BTU/Ft³	BTU/Ton
Copper (Primary)	8.82	550.2	30.8	111.8
Aluminum (Primary)	2.56	159.7	13.8	173.3
Steel (Raw)	7.8	486.6	4.7	19.2
Plastics (Average)	0.95-1.7	59.3-106	2.5-6.2	83-117
Glass Containers	2.6	162.2	1.5	18.2

TABLE 5.4 ***Comparativ.e Material Costs*** On A ***Volume Basis***

Material	¢/Lb	¢/In³
Nickel/Aluminum/Bronze	90	28.5
Brass (Yellow)	68	22.0
Stainless Steel	72	20.0
Zinc	38	9.7
Steel (CRES)	28	7.9
Magnesium	92	5.6
Aluminum	49	4.6
Steel (Hot Rolled Sheet)	13	3.7
Fiberglass Resin	50	3.1

5.3.2 ***Future Availability of Materials***

Plastics availability is dependent upon petroleum availability. During the oil embargo, certain plastics were in short supply. Since then plastics have been readily available. The plastics industry has been assured by the U.S. Office of Allocations that it will obtain a pre-allocated share of petroleum for conversion into plastics should another oil shortage occur.

5.3.3 ***Trends in Metals and Plastics Prices***

The trends in metals and plastics prices were obtained by contacting the appropriate companies involved. Trends were given by the suppliers in terms of percent increase per year over the years 1976-1986.

The metal industry has announced a 6% increase for 1977 and a 6%/yr increase in price is also estimated through 1980. With the anticipated price increase in petroleum (10%) coupled with increased labor demands. this 6%/yr estimated increase may well reach 8%/yr over the 1976-1980 period. Plastics prices will also be influenced by-oil prices but since they are not as energy dependent, the amount of price increase is not expected to exceed 5%/yr through 1980.

- ***Metal Price Trends***

Pricing for six metals is contained in Table 5.5 for a period encompassing three years. It shows the following net changes for 1974-1976:

Melal	*Price* Change
Magnesium	+ 55.9%
Steel	+ 47.4%
Aluminum	+ 22.5%
Stainless Steel	+ 16.1%
Zinc	– 5.0%
Brass	- 22.0%

The wide range of price shifts indicates that future price projections are sensitive to many factors. Nevertheless, the prime manufacturers of metals responded with predictions that are presented in Table 5.6.

• ***Plastics Price Trends***

The plastic other than polyvinyl chloride which will achieve the largest usage in shipbuilding will be fiberglass reinforced plastic (FRP). Price projections for FRP and for other, selected high performance plastics have been obtained from their manufacturers and are contained in Table 5.7.

5.4 Flammability, Smoke, and Toxicity

While much progress has been made in selectively modifying plastics to be self-extinguishing, these products are organic in nature and will support combustion in the presence of a flame. However, when the flame is removed. the plastic no longer burns.

The amount of smoke generated during fire is dependent upon the particular plastic under test. The National Bureau of Standards (NBS) has developed a smoke density chamber to assess the extent of smoke generated under controlled conditions.

The NBS is actively working to set standards on toxicity from decomposition products resulting from fire:

Data concerning flammability of fiberglass pipe was recently published.[3] While the flame spread rate exceeded

TABLE 5.5.

Past Price Trends for Selected Metals (1974-1976)

	¢/Lb.			¢/In³		
Metal	1974	1975	1976	1974	1975	1976
Brass. Yellow	83	58	68	26	19	22
Magnesium	69	82	85	4.0	5.4	5.7
Stainless Steel	62	72	72	18	21	21
Aluminum	40	45	49	3.7	4.2	4.9
Zinc	40	43	41	9.4	10.1	9.6
Steel	19	25	25	5.4	7.1	7.1

TABLE 5.6

Price Trends for Selected Merals (1976-1980)

	¢/Lb.		%Average Annual Increase	¢/In³	
Metal	1976	1980	1976-1980	1976	1980
Magnesium	92	104	3	5.6	6.4
Stainless Steel	72	88	5	20	25
Brass Yellow	68	82	5	22	26
Aluminum	49	64	7	4.6	6.0
Zinc	38	46	5	9.7	11.8
Steel	28	37	7	7.9	10.4

TABLE 5.7

Price Trends for Selected Polymers (1974-1980)

	¢/Lb				¢/In³				% Av. Annual Increase	
Polymer	1974	1975	1976	1980	1974	1975	1976	1980	1974-1976	1976-1980
Polysulfone	160	200	200	262	6.9	8.6	8.6	11.3	11.8	Approximately 4.5%
Polycarbonate	90	100	103	135	3.9	4.3	4.5	5.9	6.8	
PBT	86	92	102	134	3.7	4.0	4.8	6.3	9.5	
Nylon 6/6	78	100	108	141	3.2	4.1	4.1	5.4	17.5	
Noryl	71	75	89	116	2.8	2.9	3.4	4.5	11.8	
Polyacetal	60	78	86	113	3.1	4.0	4.4	5.8	19.6	
ABS	41	41	47	69	1.5	1.5	2.0	2.8	6.8	6.7
FRP	38-50	34-46	36-50	44-61	1.6-2.6	1.8-2.9	2.7-4.6	3.5-6.0	no change	5.1

[3] "Glass Reinforced Plastic (GRP) Piping for Shipboard Applications" by George F. Wilhemi and Henry W. Schab. Naval Engineers Journal. April 1977 pp. 139-160: reprinted in Appendix C.

the acceptance standard of 25. surface treatments reduced the flame spread rates to 25 or less:

Surface Treatment	*Flame Spread Rate (ASTM E162-67)*
1. Untreated	79
2. Intumescent Coated (10 Mils)	25
3. Mastic Coating (31 Mils)	22
4. Aluminized Ceramic Insulation (500 Mils)	0
5. Standard for Acceptance (MIL-P-0015280F (SHIPS)	≤ 25

Using the NBS smoke chamber for measurement of smoke generated during fire, the following values were obtained for fiberglass pipe:

Surface Treatment	*Optical Density (NBS)*
1. Untreated	251
2. Untreated	328
3. Untreated	278
4. Intumescent coated	210
5. Standard for acceptance (MIL-P-O015280F (SHIPS)	≤ 250

The flammability study also contained a report of the analysis of hazardous gases generated during the burning of "glass reinforced plastic (GRP)" pipe which states that ". . . the concentration of gases generated from GRP piping in a shipboard fire situation would not be considered dangerous for personnel exposures of up to 4-hours duration. The general conclusion from this analysis is that gaseous products of decomposition contributed by GRP piping would not seriously affect personnel escaping from or engaged in fighting a shipboard fire." Further, the report adds that "work is currently underway to determine the effects of intumescent coatings on smoke toxicity".

6.0 *SHIPYARD PRACTICES AND PROSPECTS FOR PLASTICS*

6.1 *Interface of the Plastics and Shipbuilding Industries*

Regarding fiberglass, a large industrial market already exists for chemical resistant pipe. Thus the development of fiberglass pipe for greater use in ships requires some product modification but not involved research. The fiberglass bathrooms and stall showers used in the construction industry also do not require much modification for use in ships. In the case of chocking compounds, epoxy resins have long been used as casting resins, particularly for electrical applications. So, the research effort to formulate a special epoxy chocking compound was not a large project.

It is most often the manufacturer of a specific polymer who performs the prerequisite research to develop an application when a potential market justifies investment. Polymer fabricators are usually small companies with limited research funds and their promotional efforts are targeted at existing or high probability applications.

It is apparent that usage of plastics in ships, generally, was a simple extension of existing industrial applications. An alternate and more effective approach is for the shipbuilding industry to sponsor applied research which would produce:

- performance standards for particular products such as plastic pipe and chocks.
- matching test specifications which would facilitate determinations whether products made from plastics conform to the standards, and
- specific proposals for incorporation of these standards and test specifications into the U.S. Coast Guard administered Code of Federal Regulations and the American Bureau of Shipping Rules. [1]

Until there is definitization commensurate with the foregoing, detail designers will continue to be reluctant to risk new applications of plastics in ships.

6.2 *Prospects for Future Use of Plastics*

As noted in Table 6.1 there are at least 14 well" established uses for plastics in large commercial ships. The suitability of plastics for these uses has been well demonstrated although they are not now approved for every potential application. Applications which have had little or no use in shipbuilding are also listed and their potential for future use is rated.

6.2.1 *Approved but Use is Limited*

"Polyvinyl chloride (PVC) pipe is approved and has been used in limited quantities for many years. However. the regulations say that it must be exposed. i.e.. not concealed behind partitions. Exposed piping is objectionable for aesthetic reasons. Earlier objections about PVC pipe concerned leaks but it was later found that proper joint cementing techniques were not used. The cost for installed PVC pipe was said to be less than for steel provided there were no jurisdictional disputes. Some foremen favored PVC pipe because no welding is required: this could be very important in certain areas.

Fiberglass ballast pipe has been used in a few ships. Some early difficulties were encountered with couplings: this has been overcome. Reportedly Mobil has been successfully using fiberglass pipe in 4 to 12" diameter sizes over the last 8 years for both oil and seawater ballast systems. Reportedly Maritime Overseas Corporation successfully used it for 6" diameter tank stripping lines. Some failures experienced when hauling grain are believed to have been caused by insufficient pipe hangers.

Deck drains of either PVC or fiberglass should be given more consideration as low cost functional items.

Fiberglass stall showers have been used in some ferries and tugs but very few have been installed in ocean going ships. Traditionally large ships feature melamine faced joiner panels and thus a comer serves, requiring only a stainless steel wing to complete the enclosure. The comparative economics of fiberglass stall showers have been discussed in Section 2.4. Some naval architects have been and are currently recommending fiberglass stall showers. The prime joiner or outfitting companies are basically metal companies and have little or no expertise in plastic manufacture and state that they do not intend to develop this expertise unless competition from plastics threatens their current business.

Modular bathrooms have recently been installed in U.S. tankers. In one case staterooms were assembled ashore as independent modules.

Hardware is one application area that should be studied. In U.S. ships chrome plated brass is still commonly used. For those uses where the structural requirements are not paramount plastics will suffice at lower cost, and probably will have longer service life in a corrosive area. However. standardization would be necessary in order to justify the cost for injection molds.

[1]From comments by L. D. Chirillo. Naval Engineers Journal. June 1977. pp. 74-75: reprinted in Appendix C.

Reefer boxes for frozen foods are being supplanted with portable self-contained freezer boxes (20' x 20' x 8'). The construction of these boxes is fiberglass/polyurethane foam/polyurethane. The rigid polyurethane foam is 3" thick. Similar boxes are also built for chilled vegetables. Boxes for storage of dry foods have a fiberglass/plywood construction. Such are being used in new LNG and RO/RO ships.

TABLE 6.1 ***Prospects for Plastics in Shipbltilding***

	Plastic Status For Applications		
	Approved but Use is Limited	Not Used	
Application		Should Be Investigated	Probability Of Suitability
Pipe (fresh and salt water)	X		
Pipe (stripping line-tanker)	X		
Pipe (Ballast) (a)	X		
Deck Drains	X		
Stall Showers	X		
Modular Bathrooms (a)	X		
Safety Treads	X		
Hardware (b)	X		
Electrical Tool Housings	X		
Fairwater	X		
Protective Covers	X		
Awnings	X		
Self Contained Refriq. Boxes	X		
Curtains	X		
Chairs (Molded)		X	High
Tables (Molded)		X	High
Grab Bars (shower stalls)		X	High
Vent Pipes		X	High
Rain Down Drains (Decks)		X	High
Airport Shroud		X	High
Lockers (buoyant work vests)		X	High
Lockers (on deck)		X	High
Spare Parts (plastic wrap)		X	High
Impellers (small pumps)			High
Partitions (toilets)		x	Mod.-High
Sinks (staterooms)		x	Mod.-High
Laundry Tubs (FRP)		X	Mod.-High
Storage Bins (food) (FRP)		X	Mod.-High
Linen Lockers		X	Mod.-High
Doors (onto Deck)		X	Mod.-High
Glazing		X	Mod.
Electric light plate			Mod.
Electric socket plate		X	Mod.
Built-in Wardrobe		X	Mod.
Ladder (Lifeboat gunwale)		X	Mod.
Sound Control (Foam)		X	Mod.
Ship Propeller		X	Mod.
Conduit (elec. wires)		X	Low
Hatch covers (cargo space)		X	Low
Teflon Launchways		X	Unregulated
Plastic Tote Boxas (c)		X	Unregulated
Plastic Pallets (c)		X	Unregulated
Plastic Strapping (c)			Unregulated
Shrinkwrap (c)		x	Unregulated
Adhesive for Staging		X	Low
Sterntube Bearing		X	Mod.

(a) Approved on a spot basis
(b) For push plates, key tags, etc.
(c) ,For intraplant movement of parts

6.2.2 Worthy Of Investigation

The furniture in the accommodation areas in commercial ships, except for passenger vessels, is not regulated as to flammability. In some cases wood furniture is used. However,wherever the outfitting subcontractor has been basically a metal company. metal case goods, chairs. and beds are usually supplied.

When sheet metal is used, furniture is limited to case goods. i.e.. box design. For designs other than case goods, plastics will probably be more productive than sheet metal.

When corrosion resistance is specified for weather deck lockers. fiberglass will probably be more productive.

spare parts could be beneficially stored in plastic shrink wrap, keeping the parts free from dirt, moisture, etc., and ready for immediate use.

Grab bars in shower stalls can be made from fiberglass, glass-reinforced nylon or polypropylene, and be cost competitive with metals.

Fiberglass partitions between toilet stalls would be less costly and require less maintenance than stainless steel. Lavatory sinks for an individual stateroom. for 1-2 men, receive very little abuse and molded plastic sinks should be more than adequate.

Fiberglass should be considered as a cost effective substitute for stainless steel shelving.

Since hardwood doors which lead to weather decks are permitted,[2] a more maintenance free, and initially lower cost, door could probably be made using fiberglass over a low grade wood substrate.

As to potential uses for plastics in the shipyard itself. Teflon launchways were suggested. While this maybe functionally a good application, the economics for Teflon against those for greased launchways is seriously questioned. An interesting Russian article on plastic lubricants for launchways is contained in Appendix F.

The prospects of using an epoxy adhesive for staging clips was investigated because of the labor involved in welding clips in place, chipping them off after use, grinding smooth. and applying a protective coating. The epoxy adhesive when applied to two clean metal surfaces will exhibit 1000 psi shear lap strength. Epoxy adhesives are used in many critical applications in aircraft However. the clip would have to be held or clamped in place during the cure. The recommended cure time is 24 hours at a temperature no lower than 60° F. Excessive humidity can also influence the bond. Hence, this particular application is not practical in view of the many factors that can influence the reliability of the bond and hence might endanger the workers' safety.

One shipbuilder suggested that the awareness of plastics in shipbuilding should be increased. He stated that a certain amount of apathy toward new applications exists because of the small prospect for dollar returns for any particular application. But, taken collectively, there maybe some savings by active investigation on the part of the shipbuilding industry. It was felt that such development efforts could best be handled by the Ship Production Committee of the Society of Naval Architects and Marine Engineers and should be the subject of future projects in the National Shipbuilding Research Program.

The savings available through the use of plastics in ships will never be fully realized until all parties to the shipbuilding process[3] acquire an understanding of plastics. particularly composites, which is equivalent to that now generally understood about steel. Thus. to assist in providing this necessary familiarity recommended references are listed in Appendix G.

[2]For example **46** CFR 72.05-25 which applies to passenger ships.
[3]**Including owners. underwriters. regulators. suppliers and subcontractors.**

APPENDIX A

PLASTICS MATERIALS —
PROPERTIES, PRICE., SOURCE

Properties and Prices of Plastics Materials

Property	Test Method	Polyethylenes (PE)	Polystyrenes (PS)	Acrylonitrile/ Butadiene/ Styrene (ABS)	Polyvinyl Chloride & Copolymers	Polypropylene	Polyurethane (thermoset)	Phenolic	Urea	Melamine
Price/lb. (average)		30-35¢	26-57¢	45-59¢	24-42¢	20-28¢	45-55¢	45¢	45¢	45¢
Specific gravity	D792	0.91-0.97	1.04-1.33	1.02-1.36	1.2-2.3	0.9-1.2	1.05-1.25	1.34-1.95	1.47-1.52	1.5-2.0
Tensile strength, psi	D638	600-5500	1500-12000	2500-19000	1000-12000	2900-14500	2000-11000	5000-18000	5500-13000	5000-10500
Elongation (%)	D638	20-1300	1.4-90	3-100	5-450	2-700	3-1000	0.2-0.8	0.5-1.0	0.3-0.8
Compressive Strength, psi	D695		4000-16000	4500-22000	900-22000	3500-8000	20,000		25000-45000	20000-35000
Flex. strength psi	D790	4800-7000	3000-17000	4000-27000	4200-18000	5000-11000	700-19000		10000-18000	9000-23000
Impact Strength (ft-lb/in. of notch)	D256	0.5-20	0.25-8.0	1.0-12.0	0.3-20	0.4-20	0.4-25	0.3-18	0.25-0.40	0.3-18
Hardness, Rockwell	D785		Mid-80	R75-120 M65-100	70(shore D) 75(shore A)	R50-110				M115
Flex. Modulus (10^5 psi)	D790	.08-2.6	1.5-4.7	1.3-13.0	Low-5	1.3-8.5	0.6-1.0	10-33	13-16	10-12
Tensile modulus (10^5 psi)	D638	0.14-.55	1.4-6.0	1.3-10.3	Low-6	1.0-9.0	1-10		10-15	11-24
Deflection temp. (°F.)	D648	90-130	175-220	170-240	Low-170	115-300	190-200	300-600	260-290	265-400
Dielectric strength	D149	420-700	300-600	350-460	225-750	450-600	400-840	140-400	220-330	200-320
Dielectric constant	D150	2.3	2.4-4.8	2.4-5.0	3.2-9.0		3.4-7.5	4.5-13	7.0-9.5	6.1-6.7
Dissipation factor	D150	< .0005	.0001-.003	.003-.015	.007-.15	.0001-.002	.008-.015	0.1-.3	.03-.04	.07-.3
Arc resist. (sec.)	D495	135-235	20-140	10-85	60-80	74-136	0.1-0.6	4-190	80-150	100-200
Transmission (%)	D1003	Translucent	Transparent	33-82	Transparent	Transparent		Opaque	Transparent	Opaque
Water absorp. (%)(24hrs)	D570	< 0.01	.03-0.6	0.18-0.60	0.04-0.8	0.01-.10	.02-1.5	0.03-1.2	0.4-0.8	0.08-0.30
Flammability	D635	Slow Burning	Self-Extinguishing	Self-Extinguishing	Self-Extingushing	Self-Extingushing	-	Self-Extingushing	Self-Extingushing	Self-Extingushing
Sunlight Effect	-	Sl-mod.	Sl. yel.	Sl. yellowing & Sl. embrittlement	Sl-mod.	Sl-great	Sl.	Darkens	Sl.	Sl.
Weak acid effect	D543	None	None	None	None	None	Sl.	V.Sl.	Great	None
Strong acid effect	D543	Great	Great	Much	None	Mod.	Great	Great	Great	Great
Weak alkali effect	D543	None	None	None	None	None	Sl.	Sl-mod.	Sl-mod.	None
Strong alkali effect	D543	None	None	None	None	Sl.	Sl.	Great	Great	Great
Organic solvent effect	D543	Selected solvents	Selected solvents	Selected attack	Selected attack	None	Sl-mod.	Sl.	Sl.	None
Cont. use temp. (°F.)								302	212	266

(continued)

Properties and Prices of Plastics Materials (continued)

Property	Test Method	Acrylic	Epoxy	Poly-acetal	Poly-carbonate	Nylon	Poly-sulfone	PPO (modified)	Poly-amide/imide	Polyester (thermo-plastic)
Price/lb (average)		0.57¢	$0.76-2.00	0.86¢	$1.03	$1.08	$2.00	.885¢	$6.00	$1.02
Specific gravity	D792	1.09-1.28	1.1-2.0	1.4-1.6	1.2-1.5	1.1-1.4	1.2	1.06-1.36	1.4	1.3-1.7
Tensile strength, psi	D638	6500-11000	4000-20000	8800-18500	7500-25000	11000-25000	10200	7800-17000	14400-26900	8300-17000
Elongation (%)	D638	3-143	1-70	2-75	1-130	3-300	50-100	4-60	3-12	1-300
Compressive strength, psi	D695	4000-19000	1000-40000							
Flex. strength, psi	D790	8900-19000	1000-60000							
Impact strength (ft-lb/in. of notch)	D256	0.3-15	0.2-30	0.7-2.3	1-18	1-3	1.3	2-5	0.7-2.5	1.0
Hardness, Rockwell	D785	M61-105	M55-120							
Flex. modulus (10^5psi)	D790	2.0-4.8	3-30	3.8-11.0	3-14	1.4-15	3.9	3.6-11.0	6-9	3-15
Tensile modulus (10^5psi)	D638	2.0-4.8	0.01-30							
Deflection temp. (°F.)	D648	155-215	115-550	215-315	265-300	155-485	345	265-300	475-525	130-415
Dielectric strength	D149	350-500	235-400	380-500	380-500	400-600	425	400-600	600	420-700
Dielectric constant	D150	2.8-4.3	3-6	3.7-3.9	2.9-3.5	3.4-12	3.1	2.6-2.9	4	3.5
Dissipation factor	D150	0.02-0.06	0.01-0.04	.005	.01-.001	0.01-0.20	.001-.003	.0004	.009	.02-.002
Arc resistance	D495	150	45-300	129-240	5-120	130-148	75-122	75		75-190
Transmission (%)	D1003	Transparent	Transparent	Translucent	85	Translucent	Trans-parent	Opaque		Opaque
Water absorp. (%) (24hrs)	D570	0.15-0.40	0.08-0.5	.20-.29	.01-0.2	1.0-1.9	0.22	0.06	0.28	0.07
Flammability	D635	Self-extin-guishing	Self Extin-guishing	Slow Burning	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing
Sunlight effect		Nil	Non-Sl.	Slight	Slight		Sl-mod.	Sl.		Sl.
Weak acid effect	D543	Nil	None	Moderate	None	Sl.	None	None	Sl.	None
Strong acid effect	D543	Great	Mod.	Great	Great	None	None	None	Sl.	Sl.
Weak alkali effect	D543	Nil	None	Slight	Moderate	Great	None	None	Sl.	Sl.
Strong alkali effect	D543	Great	Mod.	Great	Great	None	None	None	Great	Great
Organic solvent effect	D543	Selected solvents	Selected solvents	Low	Moderate	Moderate	Moderate	Moderate	Sl.	Sl.
Continuous use temp.			266		149	149	302	176-230	410	266

Properties and Prices of Plastics Materials (continued)

Property	Test Method	Polyaryl Sulphone	Aromatic Polyester Copolymers	Polyimides (Thermoplastic)	Polyimides (Thermoset)	Poly-phenylene Sulfide	Polyether Sulfone	Polyester (TS)Glass Reinforced	Polytetra-fluoroethylene (TFE)	Polyfluorinated ethylene Pro-pylene (FEP)
Price/lb (average)			$20.00		$4.50	$2.00		$0.50-0.55	$3.00	$5.30
Specific gravity	D792	1.36	1.35-1.56	1.43	1.43-1.9	1.3-1.8	1.37	1.4-2.6	2;1-2.2	2.1-2.2
Tensile strength, psi	D638	13,000	10000-12000	17,100	9000-27000	10000-21000	12,200	3000-50000	2000-5000	2700-3100
Elongation (%)	D638	13	5-10	10	1-9	0.7-3	30-80	0.5-2.0	200-400	250-330
Compressive strength, psi	D695							15000-50000		
Flex. strength, psi	D790							7000-80000		
Impact strength (ft-lb/in. of notch)	D256	1-2	0.4-1.6	0.7	0.5-17	0.3-0.8	1.6	2-30	3.0	No break
Hardness, Rockwell	D785							50-80 (Barcol)		
Flex. modulus (10^5 psi)	D790	4.0	4.5-9.0	4.8	32	6-22	3.7	10-30	0.7	0.9
Tensile modulus (10^5 psi)	D638							10-45		
Deflection temp. (°F)	D648	525	540-605	270	470-660	490-595	400	400-500	120	
Dielectric strength	D149	350	350-450	560	400-500	350	400	345-450	480	500-600
Dielectric constant	D150	3.9	2.9-3.7	3.4	4.8	3.2-3.9	3.5	3.8-6.3	< 2.1	2.1
Dissipation factor	D150	.008	.009-0.03	.006	.004	.001-.004	.004	0.01-.007	<0.0002	.0002
Arc resistance	D495	67	100-127	230	230		65	60-420	>300	> 300
Transmission (%)	D1003	Opaque	Opaque	Opaque	Opaque	Opaque	Trans-parent	Translucent	Opaque	Transparent
Water absorp. (%)(24hrs)	D570	1.1	.01-.05	0.3	0.2-0.3		0.43	0.01-1.0	0.00	0.01
Flammability	D635	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing	Self-extin-guishing
Sunlight effect		Sl.						Sl.	None	None
Weak acid effect	D543	None		None	None	None		None	None	None
Strong acid effect	D543	None		None	None	Sl.		Moderate	None	None
Weak alkali effect	D543	None		Sl.	Sl.	None		Sl-poor	None	None
Strong alkali effect	D543	None		Great	Great	None		Sl-poor	None	None
Organic solvent effect	D543	Sl.		None	None	None		None-fair	None	None
Continuous use temp. (°F.)		365				356	347	266	302	302

(continued)

Properties and Prices of Plastics Materials (continued)

	Test Method	Polychlorotrifluoroethylene (CTFE)	Poly(Ethylene-Polytetra Fluoroethylene) (ETFE)	Poly(Ethylene-Chloro-Trifluoro ethylene)(ECTFE)	Perfluoroalkoxy (PFA)	Polyvinylidene fluoride (PVF_2)
Price/lb (average)		$7.20	$6.00	$6.50	$9.00	$4.00
Specific gravity	D792	2.1-2.2	1.7	1.7	2.1-2.2	1.8
Tensile strength, psi	D638	4500-6000	6,500	7,000	4000-4300	5500-7400
Elongation (%)	D638	80-250	100-400	200	300	100-300
Compressive strength, psi	D695					
Flex. strength, psi	D790					
Impact strength (ft-lb/in of notch)	D256	2.5-2.7	No break	No break	No break	3.6-4.0
Hardness, Rockwell	D785					
Flex. modulus (10^5 psi)	D790	2.1	2.0	2.4	1.2	2.0
Tensile modulus(10^5psi)	D638					
Deflection temp.	D648	-	160	170	-	195
Dielectric strength	D149	500-600	400	490	500	260
Dielectric constant	D150	2.4	2.6	2.6	2.1	8.4
Dissipation Factor	D150	0.001-0.009	0.005	.0005-.015	.00003	0.05
Arc resistance	D495	> 360	72		-	50-70
Transmission (%)	D1003	Transparent	Transparent	Transparent	Transparent	Transparent
Water absorp. (%)(24hrs)	D570	0.00	0.03	0.01	0.03	0.04
Flammability	D635	Self-extinguishing	Self-extinguishing	Self-extinguishing	Self-extinguishing	Self-extinguishing
Sunlight effect		None	None	None	None	None
Weak acid effect	D543	None	None	None	None	None
Strong acid effect	D543	None	None	None	None	Mod.
Weak alkali effect	D543	None	None	None	None	None
Strong alkali effect	D543	None	None	None	None	None
Organic solvent effect	D543	Selected solvents	None	None	None	Selected solvents
Continuous service tem Temp. (°F.)		302				

Principal Suppliers of Commodity Plastics

Polymer	Principal Suppliers
Polyethylene (Low Density)	Union Carbide Dow Chemical Gulf Oil DuPont Northern Petrochemical U.S.I. Exxon Rexene ARCO
Polyethylene (High Density)	Phillips Allied DuPont Soltex Dow Chemical Union Carbide U.S.I. Amoco
Polypropylene	Hercules Amoco Exxon Rexene Shell
Polystyrene	Dow Chemical Monsanto Foster Grant ARCO Amoco Cosden Union Carbide
Acrylonitrile/Butadiene/ Styrene (ABS Polymer)	Borg Warner Monsanto Uniroyal Dow Chemical

Polymer	Principal Suppliers
Polyvinyl Chloride	B.F. Goodrich Diamond Shamrock Borden Chemical Tenneco Conoco
Phenolic	Ashland Chemical Durez General Electric Reichhold
Urea	Allied American Cyanamid Monsanto
Melamine	Allied American Cyanamid Reichhold
Polymethyl Methacrylate (Acrylic)	DuPont Rohm & Haas American Cyanamid
Epoxy	Ciba-Geigy Allied Diamond Shamrock Dow Chemical
Nylon	Monsanto DuPont Foster Grant
Alkyd	Durez American Cyanamid

Principal Suppliers of Engineering Plastics.

Polymer	Principal Suppliers	Tradenames
Polyesters (thermoset resin)	American Cyanamid Diamond Shamrock Goodyear Tire & Rubber W. R. Grace ICI Rohm & Haas PPG	Multiple
Polyester (thermoplastic)	Celanese DuPont Eastman General Electric	Multiple
Polyimide	Amoco DuPont Ciba Geigy Monsanto	Multiple
Polysulfone	Union Carbide	UDEL
Polyacetal	DuPont Celanese	Delrin Celcon
Polyphenyl Oxide Based Resin	General Electric	Noryl
Poly Amide/Imide	Amoco	Torlon
Polyaryl Ether	Uniroyal	
Polyether Sulfone	ICI	
Polyaryl Sulfone	3M	Astrel 360
Polycarbonate	General Electric Mobay	Lexan Merlon
Aromatic Polyester Copolymers	Carborundum Co.	Ekkcel
Polyphenylene Sulfide	Phillips	Ryton
Polytetmfluoro-ethylene	Allied DuPont ICI	HaIon Teflon Fluon
Polyfluorinated Ethylene Propylene	DuPont	FEP
Poly(ethylene-polytetrafluoroethylene)	DuPont	Tefzel
Poly(ethylene-chlorotrifluoroethylene)	Allied	Halar
Perfluoro Alkoxy	DuPont	PFA
Polyvinylidene Fluoride	Pennwalt	Kynar

APPENDIX B

NOTE : The 12 August 1977 1etter is a good example of how more knowledge permits the greater use of plastics in ships. This letter eliminates restrictions on the use of RTRP in both inert gas systems and marine sanitation devices that was expressed in the 20 April 1977 letter just four months earlier.

Regarding inert gas systems, it is likely that the change in thinking is due to the fact that, because of its excellent corrosion resistance, reinforced thermosetting resin is probably the best material for the acidic effluent piping from inert-gas scrubbers.

Regarding marine sanitation devices, it is believed that the ban on the use of plastic pipe was based upon concern for flammable vapors from decomposing waste. Reportedly the USCG'S revised thinking, which permits RTRP, is based upon U.S. Navy studies which revealed the flammable gas problem to be significantly less than expected.

With further regard to marine sanitation devices. the USCG 15 February 1977 Commandant Instruction advises field personnel and others to use a specific publication of the Canadian Environmental Protection Service for design guidance. Because the publication suggests PVC pipe for waste, drainage, air supply and venting, it is probable that the USCG will accept PVC pipe, in addition to RTRP, if usage is in the context of the Canadian guidelines.

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

MAILING ADDRESS:
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WASHINGTON, D.C. 20590
PHONE: (202) 426-2160

16703/46 CFR 56.60-25
10320/1

2 0 APR 1977

Todd Shipyards Corporation
Seattle Division
Attn: Mr. John F. Curtis
1801 16th Avenue, S.W.
Seattle, Wash. 98124

Gentlemen:

Subj : Reinforced Thermosetting Resin Pipe

Ref: (a) Your letter dated 1 February 1977

Thank you for your inquiry regarding the use of RTRp pipe in shipboard applications.

The information provided in this letter will probably not come out in the form of an NVIC, but may be incorporated in the next revision of the Marine Engineering Regulations.

Regarding the use of RTRP, the primary limiting factor in its use is fire resistance. This letter does not constitute a general approval for the use of RTRP, but rather may allow for its use only after a thorough review of the various systems where installation is desired. Minimum material and installation requirements for various systems are addressed herein. We offer the following:

Material Requirements

a. Pipe shall meet ASTM D2996 or D2997 and be compatible with the fluid carried .

b. Operating parameters are limited *to* 150 psig and 240°F, using a 5 to 1 design safety factor

c. Pipe shall be fire retardant as required by 46 CFR 56.60-25(a)(10).

Fire test procedures and reports should be submitted to the cognizant Coast Guard District Merchant Marine Technical field office.

Installation Requirements

a. RTRP may not be used in a concealed portion of any piping system, except in cargo tanks as described herein *or* as permitted in 46 CFR 56.60-25 (a) (3).

b. RTRP may not be used in any portion of a system which conveys a toxic, combustible, or flammable fluid, except for piping located inside of the. cargo tanks as permitted herein.

c. RTRP may not be used as part of the pressure or cargo containing boundary for any cargo tank or presssure vessel.

d. Penetration of any watertight bulkhead must be accomplished with the use of metallic spool pieces and be controlled with either one valve operable from above the bulkhead deck, or two valves, one located adjacent to the metallic spool piece on either side of the watertight bulkhead in compartments both of which are readily accessible. Specific exceptions are noted herein.

e. Other general requirements in 46 CFR 56.60-25 for nonmetallic materials must be followed with the following exceptions:

(i) Subparagraphs 56.60-25(a)(6) through (9) are not applicable unless the RTRP is intended for potable water senice when NSF marking is required.

Specific Systems

a. Bilge system

(i) RTRP may not be used in any portion of any bilge system.

b. Ballast or Segregated Ballast *System*

(i) RTRP maybe used in these systems and is limited to use within the engine room and pump room and cargo tanks with the following requirements and limitations:

aa. Certification must be provided showing that RTRP is suitable for the intended service (pressure and temperature limitation and chemical compatibility).

bb. RTRP may be used in cargo tanks as part of the ballast system at the end of *a* piping run. All bulkhead penetrations must be accomplished with a metallic spool piece and be controlled by a valve adjacent to the spool piece, operated from above the tank at the main deck level.

(ii) All other piping external to the tanks, engine room or pump room must be metallic.

c. Firemain or Fire Protection Systems

(i) RTRP may not be used in any portion of the firemain or fire protection systems.

Subj: Reinforced Thermosetting Resin Pipe

d. Deck Foam System

(i) RTRP may not be used in any portion of the deck foam system.

e. Cargo Tank Vent System

(i) RTRP may not be used in any portion of the vent system for a cargo tank which carries flammable, combustible or toxic fluid.

(ii) Where products other than combustible, flammable or toxic liquids are carried, RTRP may be used on the discharge side of relief valves providing the discharged product is within the pressure and temperature limitations of RTRP and is chemically compatible.

f. Cargo System

(i) RTRP may not be used in any portion of the cargo liquid or vapor system except inside the cargo tanks,

(ii) Inside the cargo tanks RTRP may be used subject to the testing and limitations indicated under Ballast or Segregated Ballast Systems.

g. Nonvital Systems

(i) RTRP may be used in nonvital systems including the following services:

aa. Sanitary System

bb. Potable Water System

cc. A/C Chill Water System

dd. Hot Water Heating System

ee. Cooling water piping for nonessential equipment

h. Vital Systems

(i) RTRP may be used in vital salt and fresh water systems when the applicable requirements of 46 CFR 56, 60-25(a) and (b) are met.

i. Inert Gas Systems

(i) RTRP may not be used in any portion of the Inert Gas System.

j. Fuel Oil Transfer System Within Tanks

(i) Same as for Cargo System.

k. Sounding Tubes

(i) RTRP may be used in construction of sounding tubes within all tanks. Tank penetrations must be accomplished with the use of metallic spool pieces, either welded or otherise suitably attached to the tank boundary.

l. Vent Ducting

(i) RTRP may not be used in any portion of the ventilation system where watertight or fire tight integrity may be compromised.

m. Marine Sanitation Devices (MSD)

(i) RTRP may not be used *in* either the MSD proper or associated piping systems where the generation or collection of flammable vapors from degenerating sewage or other decomposition process may exist.

n. Auxiliary Steam Exhaust Lines

(i) RTRP may be used for auxiliary steam exhaust lines located on deck, provided the system pressure and temperatures are within the limits set forth under the material requirements stated above.

o. Cryogenic Applications

(i) RTRP may not be used in systems with service temperatures lower than O°F,

The type of pipe joining fittings and couplings shall be in accordance with 46 CFR 56.30-40. Proprietary joints shall be authorized by the Commandant, Tests shall be conducted to insure that these joints are satisfactory for the *service* intended. Proposed tests shall be submitted for review. Joints shall not reduce the rating of the piping system.

Subj: Reinforced Thermosetting Resin Pipe

The Coast Guard's position, as expressed in paragraph two of this letter, is that the fire resistance of RTRP is minimal. In order for RTRP to be considered for use in systems from which RTRP is now excluded, it must be shown that RTRP is equivalent to steel piping. Not only does this mean that it must withstand a 1700°F fire test for approximately one hour but in addition must not contribute to the fire. If a proposal were submitted to the Coast Guard to show equivalency as :above, the following requirements of a general nature are to be followed:

a. A test set up should consist of three lengths of pipe, tested either jointly or independently. One pipe should be empty, one partially filled with fluid to a depth of one-tenth the diameter of the pipe, and one filled with fluid under a pressure commensurate with the pressure of intended service, but in no case less than 50 psig. In all three cases the ends of the pipe should be blanked so that the fluid is stationary. Each pipe should be fitted with a relief valve. The test length shall not be less than three feet. The test shall be such that actual fire conditions are approximated, and not merely that of bunsen burner, with direct localized flame impingement.

b. The length of the test should be twenty minutes for pipe intended for grades D and E combustible liquid service and sixty minutes for pipe used for grades A, B or C flammable liquid service. During the first three minutes of the test the temperature should rise from ambient to at least 1600°F. For the remainder of the test, the temperature shall not fall below this value. Temperature should be measured adjacent to the outside wall of the pipe.

c. The test must be such that it can be reproduced with a certainty of obtaining identical conditions.

d. Upon completion of the test each test pipe should be capable of withstanding a hydrostatic pressure equal to its rated pressure without failure or appreciable leakage.

Pipe support systems must be submitted for evaluation. Because the RTRP material is softer than support material in most *cases* RTRP is susceptible to wearing.

Within this letter we have addressed the broad catagory of reinforced thermosetting resin nipe and have not limited our comments to only fiberglass reinforced pipe. This *terminology* is consistent with that used in ASTM specifications where RTRP is used as the general grouping for this type of nonmetallic piping material.

The Coast Guard is not at this time considering a research and development program to establish performance or workmanship standards for RTRP. The Department of the Navy is currently conducting an extensive testing program for RTRP . We feel that these test results when they become available may strongly

influence the Coast Guard position for acceptance of RTRP in shipboard piping applications.

Should any further questions arise regarding the use of RTRP please contact this office.

Sincerely,

R. G. WILLIAMS
Commander, U. S. Coast Guard
Chief, Engineering Branch
Merchant Marine Technical Division
By direction of the Commandant

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

MAILING ADDRESS.
U.S. COAST GUARD (G-MMT-2/82)
WASHINGTON. D.C. 20590
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16703/46 CFR 56.60-25
10320/1

30 AUG 1977

Todd Shipyards Corporation
Attn: Mr. John F. Curtis
Seattle Division
1801 16th Avenue, S.W.
Seattle, Wash. 98124

Gentlemen:

Subj: Reinforced Thermosetting Resin Pipe

Ref: (a) COMDT letter dated 20 April 1977

This letter supplements reference (a) and clarifies certain areas which may be misleading or may be construed as permitting or prohibiting the use of RTRP in systems where such action is not intended. Additionally, specific regulations which pertain to the installation of non-metallic materials are cited and addressed herein:

a. The use of RTRP in nonvital systems may be permitted within the confines of 46 CFR 56.60-25(a). We note particularly that where RTRP will be used in nonvital service and is within concealed spaces in accommodation or service areas, the pipe must be boxed with "A" class divisions.

Concealed spaces are areas behind ceilings or linings or between double bulkheads. "A" class divisions are defined in 46 CFR subpart 35.57 for tank vessels, subpart 72.05 for passenger vessels and subpart 92.07 for cargo and miscellaneous vessels.

b. In reference (b), we stated that RTRP may not be used in any portion of the inert gas system. In fact, RTRP has been approved in the past for use in drain lines and overboard discharges from inert gas scrubbers and because of the highly corrosive nature of the overboard discharges, it will continue to be considered for this application.

c. Where RTRP is used in vent ducting, the requirements of 46 CFR 56.60-25(a)(c) must be met. The insurance of fire tight integrity becomes a two fold problem because not only can RTRP burn and cause a breach in a fire boundary but also can cause a significant heat input to a compartment in a fire situation which could surpass the design parameters for installed structural fire boundaries. To be considered adequately protected to insure fire tight integrity, RTRP must be enclosed by "A" class division structural fire protection.

Subj: Reinforced Thermosetting Resin Pipe

d. RTRP may be considered for use in marine sanitation devices and associated piping including vent lines. Design and arrangement drawings must be reviewed for each installation. Consideration must be given to the possibility of the collection or generation of flammable or toxic vapors. Requirements for the penetration of fire tight and water tight boundaries are addressed in 46 CFR 56.60-25(a).

e. The fire test requirements outlined in reference (a) are inadequate. Where RTRP is intended to replace required steel pipe, the RTRP must be able to withstand the full sixty minute fire test. The sixty minute test applies not only to piping intended for grades A, B and C flammable liquid service, but to all systems where steel is presently required. RTRP may not be used in fire main, fire protection or deck foam systems.

Should any questions arise concerning the use of RTRP pipe, please contact this office.

Sincerely,

R. G. WILLIAMS
Commander, U. S. Coast Guard
Chief, Engineering Branch
Merchant Marine Technical Division
By direction of the Commandant

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COMDTINST 16714.1

COMMANDANT INSTRUCTION 16714.1

15 FEB 1977

Subj : Sewage Holding Tank Design Data

1. Purpose. The purpose of this Instruction is to make field units aware of the availability of data for use in designing vessel sewage holding tanks.

2. Discussion. Certain amendments to the U.S. Coast Guard Marine Sanitation Device Regulations (33 CFR, Part 159) were published in the Federal Register on 3 January 1977 (42 FR 11). These amendments have the effect of declaring certified by definition all holding tank installations which are designed solely for the storage of sewage and freshwater at ambient air pressure and temperature. However, it can be anticipated that Coast Guard field activities will continue to receive numerous requests for information related to sizing and other design criteria for vessel sewage holding tanks. The Canadian Department of the Environment has prepared a report containing an exhaustive treatment of all aspects of holding tank design which can be used as a basis for answering such requests. This report, entitled "Development of Design Guidelines for Shipboard Sewage Holding Tanks, Report No. EPS 3-WP-76-3, February, 1976," is available without charge from:

Environmental Protection Service
Department of the Environment
Ottawa KIA 0H3
Ontario, Canada

Single copies of this report have been forwarded under separate cover to all Marine Safety Offices, Marine Inspection Offices and Marine Inspection Detachments.

3. Action. Field personnel involved in providing information to vessel designers should familiarize themselves with this publication and use it as a basis for providing design guidance. Vessel designers and builders should be encouraged to obtain copies directly from the Canadian Government for their own use.

W. M. BENKERT
Chief, Office of Merchant Marine Safety

DIST: (SDL 104)

A: None
B: b(3); c(20); e(lO); f(15); g(11);
h(6); j(2); pq(l); r(7)
C: emo(2)
D: 1(2)
E: mno(2)
F: p (1)
List CG-10

APPENDIX C

GEORGE F . WILHELMI & HENRY W. SCHAB

GLASS REINFORCED PLASTIC (GRP) PIPING FOR SHIPBOARD APPLICATIONS

THE AUTHORS

Mr. George F. WIlbelmi *is a Project Engineer in the Machiney Dynamics Division, Propulsion and Auxiliary Systems Department, at the David W. Taylor Naval Ship Research and Development Center, Annapolis, Md. He has been at DTNSRDC/Annapolis since 1965, and has participated in the Co-operative Education Program. Mr. Wilhelmi graduated from Drexel Universiy in 1969, receiving his BS degree in Mechanical Engineering, and since then has been involved in the structural, hydradynamic, and thermodynamic aspects of marine fluid systems.*

Mr. Henry W. Schab, *a Mechanical Engineering graduate of the University of Maryland, has been engaged in Navy Research and development projects at the David W. TayIor Naval Ship Research and Development Center, Annapolis Laboratory for over 25 years. His principal areas of research have been in gas turbines, fuels and lubricants, noise and vibration reduction, and auxiliary systems. For the past nine years he has been the Technical Coordinator at the Annapolis Laboratory for the Navy's Hydrofoil Development Program. Mr. Schab is a registered Professional Engineer in the State of Maryland, the Author of previous papers published in the Naval Engineers Journal. and a member of A. S.N.E. since January 1960.*

ABSTRACT

The widespread acceptance of Glass Reinforced Plsatic (GRP) Piping by industry has not been paralleled by Navy shipboard applications due to lack of technical information concerning performance characteristics of the material in the shipboard environment. The need for a corroasion-free, lightweight, low cost alternative to metallic piping materials aboard advanced Navy ships provided an oppartunity to begin investigations with GRP Piping In the areas of fire performance, meehanical properties, cyclic fatigue characteristics, shock performance, flexible compatible couplings, erosion redstance, marine fouling control systems, and joint inspection techniques.

Results of investigations to date have provided encouragement for current applications of GRP Piping in advanced Navy ships, and for future applications throughout the entire surface-ship fleet. Several diversified GRP pipe, fitting, and joining concepts employed by various manufacturers are currently being investigated to provide the performance criteria necessary to develop a military specification ensuring required characteristics for general shipboard service.

INTRODUCTION

THE *SEARCH* FOR NEW MATERIALS THAT ARE lightweight, more corrosion resistant, and less expensive is a never ending process. In the marine field, naval architects and engineers continually live and wrestle with the important problems of weight, cost, and maintenance requirements. The development of high performance, weight critical ships, such as naval Hydrofoils and Surface Effect Ships, has greatly intensified these material requirements and has led to more extensive consideration of alternative approaches such as nonmetallic piping in seawater and freshwater systems.

Of the present metallic pipe alternatives, Glass Reinforced Plastic (GRP) of the epoxy-resin filament-wound type is ***one*** of the more widely used material combinations. This type of pipe has been both successfully (and unsuccessfully) applied to many industrial systems in which metallic piping suffered severe corrosion. Misapplication and consequent system failure is likely to occur if GRP is directly substituted for metallic piping without designing around its particular properties. This is particularly true for shipboard applications where consideration must be made for vibration, shock, fire resistance, exposure to external forces, marine fouling, et cetera.

The objective of the present program is by experiment to investigate GRP pipe, fittings, and bonded joints in areas such as fire resistance, joint quality, fatigue performance, et cetera. to provide the basic data naval engineers will require to make sound decisions regarding application of the material in shipboard systems. The majority of work conducted to date at the David W. Taylor Naval Ship Research and Development Center, Annapolis, Md., as discussed in this paper was sponsored by the NavaI Sea Systems Command and directed toward advanced ship applications, but current work at the Center is geared toward general NAVY surface ship applications and the development of a military specification for shipboard service in water systems rated up to 150 lbs/in^2 and 200°F.

The reader is cautioned that the results presented in this report are based on investigations conducted with ***one*** candidate system, and they do not necessarily represent performance characteristics (which may be superior or inferior) of the wide variety of commercially available GRP piping systems. Several diversified GRP pipe, fitting, and joining concepts employed by various manufacturers are currently being investigated to provide the performance criteria necessary to develop a general ship specification which would provide a product qualification standard open to ***all*** manufacturers.

Background

General

Glass Reinforced Plastic pipe of the epoxy-resin filament-wound type is designed to combine the strength of fiberglass filaments with the chemical resistance of thermosetting epoxy resin. The composite pipe wall is filament wound under tension on rotating cylindrical mandrels, by either wet winding or pre-impregnated tape winding techniques. The piping material used for these investigations contained approximately 32% epoxy resin by weight and was reinforced with continuous strands of "E" glass wound at an angle of approximately 55° to the pipe axis over a resin-saturated, chemical-resistant "C" glass reinforced liner. Generally, the glass fibers are oriented to optimize strength in the longitudinal and circumferential directions when the pipe is subjected to internal pressure. That is, the reinforcement provides approximately twice the strength in the hoop direction as in the axial direction to coincide with the stress distribution. This strength pattern is obtained in many products by employing a single winding angle as described above, but it can also be achieved by alternately winding two hoop layers and an axial layer of reinforcement, as in dual angle product lines produced by another leading manufacturer.

Compression molded fittings made from epoxy molding compounds with random fiber reinforcement are available from most manufacturers along with some filament wound in-line fittings (sleeve couplings. reducers. threaded adapters, et cetera). A complete line of filament wound fittings include elbows, tees, and flanges is currently produced by only one manufacturer. There are several types of adhesive-bonded joining systems available including semi-tapered, fully-tapered, and straight socket-spigot connections. The semi-tapered system consists of a straight spigot (usually a GRP pipe shaved a desired distance with a manual or power driven tool) and a tapered bell (usually a fitting socket which has been factory tapered with an internal shoulder that acts as a pipe stop). The two are bonded together with a compatible epoxy adhesive. The fully tapered system consists of matching tapered bonding surfaces, formed between factory tapered fitting sockets and field tapered pipe ends, which are joined with an extremely thin line of compatible epoxy adhesive. With the straight nontapered system, tolerance becomes more critical and the flow of epoxy adhesive more difficult to control (Figure 1). Joint adhesives are available from most manufacturers in pre-measured kit form. If ambient temperatures are below 60°F, heat assisted curing becomes necessary and electric heating blanket or self contained chemical heat packs can be used. With some systems heat assisted curing is always recommended regardless of ambient temperature.

The GRP piping industry currently suffers from a severe lack of standardization. Pipe, fittings, and adhesives purchased from one manufacturer are generally not interchangeable with products from another. Product lines vary in rated operating pressure and temperature, and there are numerous joining techniques as previously discussed. The only existing military specifications for GRP pipe and fittings (MIL-P-22245A, Yards and Docks, 29 April 1970 and MIL-P-28584, 15 April 1975) were developed for underground shore side installations and were not intended for shipboard installations. These specifications provided no control of many of the characteristics, such as fire resistance. smoke, et cetera, required for shipboard service.

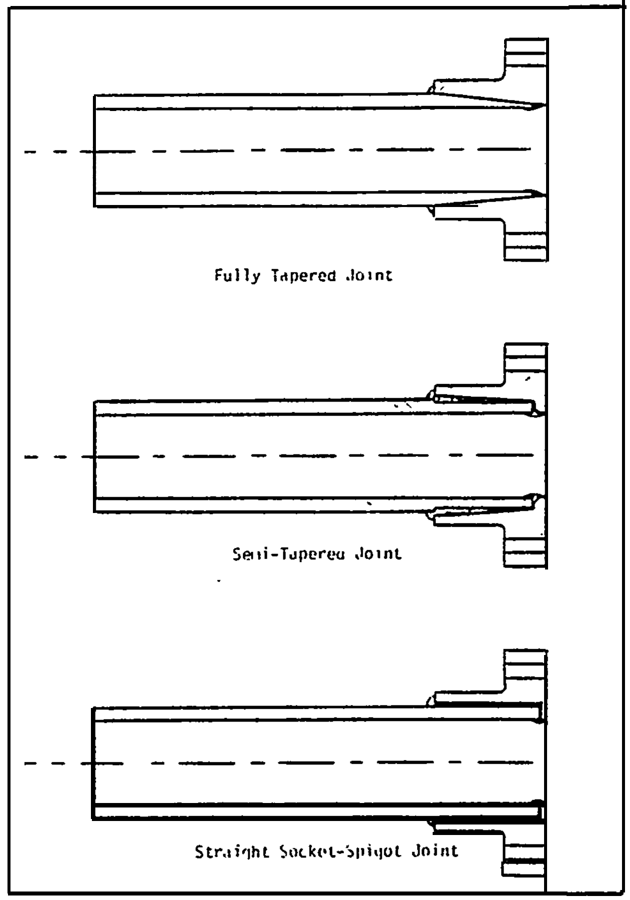

Figure 1. Adhesive Bonded Joining Techniques.

Some basic material properties of various thermoplastic, GRP thermosetting, and thin-walled metallic piping are compared in TABLE 1. Thermoplastic materials such as polyvinyl chloride (PVC) and chlorinated polyvinyl chloride (CPVC) are extremely temperature-sensitive, and by their thermoplastic nature will not survive in a fire situation. For this reason, and for concern over toxic products of combustion. thermoplastic piping materials are not considered suitable for general shipboard application.

Weight and Cost Considerations

Design plans being developed for seawater and fresh-water piping systems aboard future naval surface effect

TABLE 1

MATERIAL PROPERTIES FOR 2-INCH SGWATER PIPING

Properties	Thermo-plastic CPVC High Temp (Sch 40)	GRP THERMOSET[1] I	GRP THERMOSET[1] II	GRP THERMOSET[1] III	Metallic: Aluminum Alloy 6061-T6 (Sch 10)	Metallic: Cu-Ni 90/10 (Class 200)	Metallic: Titanium Unalloyed (Sch 10)	Metallic: Stailess steel Type 316 (Sch 10)
Outside diameter, in.	2.375	2.375	2.375	2.375	2.375	2.375	2.375	2.375
Wall thickness, in.	0.154	0.140	0.114	0.080	0.109	0.083	0.109	0.109
Weight/foot, lb	0.75	0.80	0.60	0.60	0.91	2.32	1.52	2.70
Maximum pressure rating for pipe at 75° F, lb/in^2	280	550	300	300	550[2]	690[2]	1100[2]	1480[2]
Maximum pressure rating for pipe at 180° F. lb/in^2		↓	↓	↓	↓	↓	↓	↓
Tensile strength at 75° F. lb/in2	7,300	8,500	9,747	30,000	38,000	44-60,000	40-80,000	90,000
Modulus of elasticity in tension at 75° F, lb/in^2	G.36x10^6	1.6x10^6	1.1x106	2.7x10^6	10.0x10^6	M. 0X106	16.0x10^6	28. 0X10^6
Coefficient of expansion, in/in/°F	4.4x10^{-5}	0.85x10^{-5}	1.14X10^{-5}	. 69%10^{-5}	1.30s10-^{5}	0.95X10^{-5}	0. 47X10^{-5}	0.89x10^{-5}
Thermal Conductivity, Btu/hr/ft^2/°F/in.	0.96	2.30	2.76	1.70	1070.0	324.0	126.0	112.8
Joining techniques	Solvent & thermal welding	Semi tapered bonded joint	Fully tapered bonded joint	fully tapered bonded joint	Welded & Swaged joints	Welded & brazed joints	Welded & Swaged joints	Welded &. Swaged joints
Available nominal size range, in.	1/4-6	2-12	1-12	2-16	1/2-6	1/4-12	1/8-6	1/2-36

(1) GRP - Fiber glass filament-wound thermoset material.- 3 different manufacturers

(2) Maximum pressure rating for pipe calculated using Barlow's formula with no allowance for corrosion or threading.

ships call for pipe sizes ranging up to and including 6-inch nominal_ diameter. This size-range represents a large percentage of the water piping systems currently found aboard conventional naval surface ships. A weight comparison of GRP and various metallic piping materials in the 1- through 6-inch size range is presented in Figure 2. This chart compares GRP piping to Schedule 10 aluminum alloy, Schedule 5 titanium, Schedule 5 stainless steel, and Class 200, 90-10, copper-nickel. Schedule 10 aluminum was previously the "standard''material in all naval hydrofoil seawater and freshwater systems. Schedule 5 is the thinnest walled piping in titanium and stainless steel materials currently available commercially. Class 200 copper-nickel is the thinnest walled, lightest pipe suitable for l5Opsig seawater systems under MIL-T-16420J (Ships).

The comparison in Figure 2 clearly indicates that, on a weight per foot basis, GRP is the lightest piping material. However, in order to determine whether GRP can actually reduce the overall weight of a complete shipboard piping system, which includes fittings, valves, bulkhead penetrators, et cetera, a detailed weight analysis is required. Results of a GRP piping feasibility study in 1971, conducted by the Naval Ship Engineering Center (NAVSEC) for the PatroI Frigate (PF) Class of ships. provides a basis for comparison. Results of this study showed that a GRP system with fittings was roughly one-third the weight of a steel or copper-nickel system. and that its installation would result in a weight saving of approximately 22 tons per ship considering only piping of 6-inch and smaller diameters. The detailed weight estimates were based on weight summaries by Gibbs and Cox for the DE-1054 in which only grades B&C shock rated piping (MIL-S-901C) was considered. Weight savings were assessed by substituting GRP piping for sections of the plumbing, flushing, drainage, venting, tire-main, sprinkling, potable water, seawater, weather deck drainage, fuel, sounding, overflow, air escape, trim, and ballast systems, all of which were normally fabricated from copper, copper-nickel, steel, and aluminum materials.

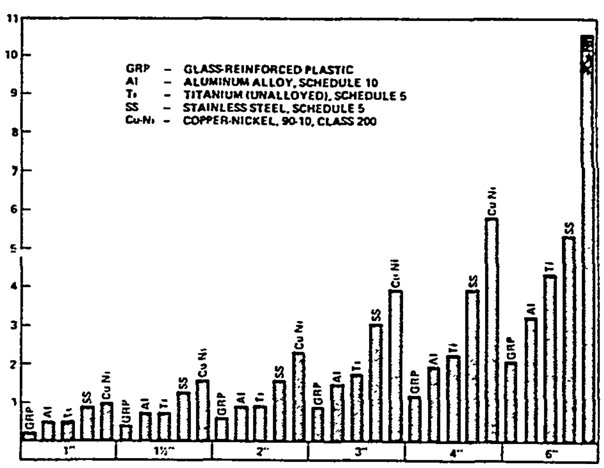

Figure 2. Weight Comparison of Various piping Materials.

TABLE 2

WEIGHT ASSESSMENT FOR SW SYSTEM ABOARD PLAINVIEW (AGEH-1)

ITEM	EXISTING ALUMINUM WEIGHT, (lbs.)	REPLACEMENT GRP SYSTEM WEIGHT, (lbs.)
Piping and Tubing	616.0	360.3
Valves	847.6	505.6
Flanges	373.7	254.3
Fittings (Elbows, Tees, Crosses. Reducers, etc.)	350.3	408.6
Estimated 20%. Additional Fittings Required for AGEH 1 Replacement	—	82.0
10 Bulkhead Penetrations		30.6
TOTAL	2187.6	1641.4

In 1975 a weight assessment was made for the replacement by GRP of the deteriorated aluminum seawater system on AGEH. TABLE 2 clearly shows the weight reduction advantage offered by a GRP system.

A cost comparison of GRP and the various metallic piping materials is shown in Figure 3. Costs are in terms of October 1974 dollars, based on minimum orders of 100 feet of each pipe size. Excluding the 6063-T6 aluminum piping, GRP ranks as the least expensive pipe on a per foot basis over the entire sue range. Aluminum alloy 6063 was used in this comparison because it was the single alloy readily available in the form of Schedule 10 pipe. However, this alloy would not be recommended for seawater piping applications. The cost of Schedule 10 aluminum piping in any other alloy is expected to be significantly greater since production set-up charges or minimum orders of 1 to 2 thousand pounds of each size pipe would be required. The previously mentioned NAVSEC GRP Feasibility Study indicated that the cost ratio of an installed GRP piping system in the 2 thru 6-inch diameter range was 0.32 for GRP/CuNI and 0.96 for GRP/Carbon Steel.

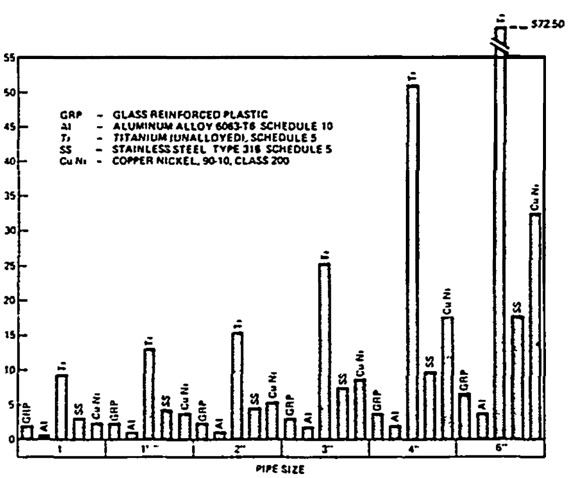

Figure 3. Coat Comparison of Various Piping Materials.

In another analysis dealing with the installed cost of corrosion resistant piping in the 2 thru 6-inch size range, MARSHALL and BRANDT [1] show that the *cost* of a 500-foot complex GRP piping system ranged from 58% to 83% of the cost of a Schedule 40 aluminum system. In the same analysis, GRP was compared to Schedule 5, 316 stainless steel, and the installed cost varied from 44% to 50% of 316 SS.

A recent study was conducted by the National Steel and Shipbuilding Co. [2] to examine the design and installation problems and comparative economics in substituting fiberglass for steel in actual designs of shipboard piping systems. Preliminary results predict cost savings of 15% and 20% for cargo oil and clean ballast systems respectively, if GRP piping is used in place of steel in a modem 90,000DWT San Clemente Class Tanker.

The general conclusion of these weight and cost analyses is that GRP ranks as the lightest and least expensive "corrosion resistant"' piping material that can be applied in shipboard systems.

Shipboard Installations

In 1969 three test sections of plastic piping material were installed in the seawater systems aboard the NAVY'S hydrofoil Highpoint (PCH-1). This material replaced aluminum piping which had suffered severe pitting and corrosion (See Figure 4). These sections consisted of both GRP and PVC piping along with CPVC ball type valves which were exposed to conditions of relatively high temperature and flow rates, stagnant seawater exposure, and throttled flow. In addition, one of two main seawater boost pumps was modified to contain a PVC impeller. The results of this evaluation were most encouraging. After nearly two years of service operation, inspection of the test sections showed that the inner surfaces of piping and valves were in excellent condition with no build up of scale or deposits. On the basis of these results, the entire seawater system in Highpoint was replaced by GRP piping material during a scheduled major modification period in 1973. To this date no problems with the system appear to exist.

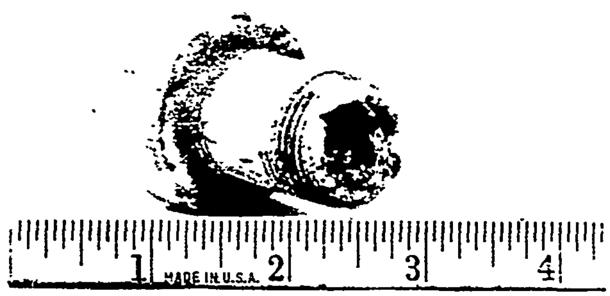

Figure 4. Corroded Aluminum 6061-T6 Piping.

In 1973 the potable water system aboard *USS Flagstuff* (PGH-1) was replaced with GRP and plastic components due to extensive corrosion of the original aluminum alloy system. In addition, the water had acquired a bad taste which was traced to an accumulation of corrosion products and other material in the aluminum storage tank. With the new system no problems have been reported to date.

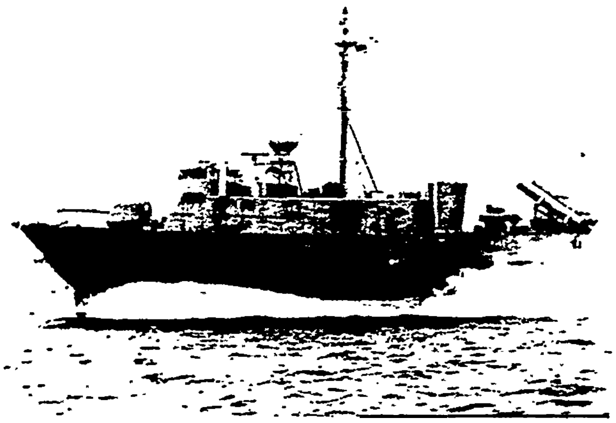

Figure 5. USS PEGASUS (PHM-1).

Figure 6. Navy Barge Installation.

During 1975 the entire aluminum alloy seawater system aboard the 300-ton hydrofoil *Plainview* (AGEH-1) was replaced with GRP piping material. In this installation over 500 joints were bonded, and pressure tests of these sections after installation showed only five leaks, all of which were readily repaired.

The first extensive installation of GRP piping was made aboard the NAVY'S newest hydrofoil, the 235-ton PHM-1 *(Pegasus),* Figure 5. GRP is employed in the seawater, freshwater, potable water, chilled water, bilge water. waste water and sewage water systems. Over 2,000 joints were fabricated and installed in this "first" major installation. After the resolution of early installation problems, the systems are performing satisfactorily.

GRP piping also has been applied successfully in other recent naval. shipboard applications including a

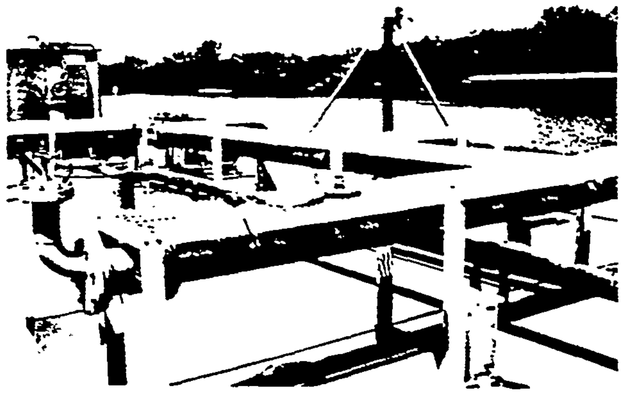

Figure 7. GRP Piping on the Deck of a YON Class Fuel Barge.

small fleet of naval service barges. In eleven non-self-propelled steel fuel barges of the YON Class, GRP piping in the size range from 3-to 10-inch diameter was installed both above and below the weather deck (Figures 6 and 7). Twenty two pollution barges of the SWOB Class also have been equipped with GRP material in all fuel and sewage cargo piping systems.

In commercial shipboard applications, GRP has been and is being used in services such as saltwater ballast, cargo oil, saltwater cooling, condensate lines, stripping lines, sewage, et cetera. Overall shipboard usage is not prevalent, however, because of restrictive U.S. COAST GUARD Regulations.

AREAS OF INVESTIGATION

Fire Performance

Evaluation fo the fire performance characteristics of GRP piping material requires consideration of various factors including surface flammability, smoke. production, toxicity of gaseous products of decomposition, and capability of the piping system to remain functional in a full-scale fire under dry, stagnant, and flowing water conditions. Therefore, experiments were conducted with small and large-scale test apparatus to measure these factors and to determine the effectiveness of various lightweight fire-protective measures including intumescent paints, mastic coatings, ceramic felt insulation. and fire-protective covers. The protective systems investigated were limited to those which would not increase the weight of the piping above that of bare Schedule 10 aluminum piping. Where possible, standard test methods. such as ASTM E162 (surface flammability of materials using a radiant heat energy source) and the National Bureau of Standards smoke density chamber, were used to determine performance so that measured properties could be compared to established acceptance levels for materials now in NAVY shipboard service. The full-scale fire tests were designed to simulate conditions that could be encountered in a

with GRP pipe, fittings, and joints along with conventional metallic piping materials represented by 90/10 copper-nickel (with silver-brazed bronze fittings) and aluminum alloy 6063-T6. Steady-state heat-transfer analyses were made to insure that fire tests conducted with water-filled 1- and 2-inch diameter GRP assemblies would adequately represent the performance of large GRP pipes up to 6 inches in diameter.

Surface Flammability

Experiments were conducted with radiant panel apparatus to determine the surface flammability of GRP piping with and without various lightweight fire-protective measures. A brief description of the radiant panel test is summarized from HILADO [3] as follows:

> "The radiant panel test employs a radiant heat source consisting of a 12- by 18-inch vertically mounted porous refractory panel maintained at 1238 ± 7°F. A specimen 18- by 6-inches is supported in front of it with 18-inch dimension inclined 30° from the vertical. A pilot burner ignites the top of the specimen, 4¾ inches away from the radiant panel. The temperature rise recorded by stack thermocouples, above their base level of 400°F, is used as a measure of heat evolution."

The GRP specimens for these tests usually consisted of three, and in some cases two, 110° sections of 2-inch-diameter GRP pipe mounted in a standard 6- x 18-inch steel frame. Because the specimens were pipe sections and not flat panels, the experiments did not strictly conform to ASTM E162-67. However. this test configuration more closely approximated conditions expected *in* a shipboard fire, and it caused no significant variation in radiant heat flux nor problems with edge ignition effects. Results of the surface flammability test are summarized in TABLE 3. Test conditions and procedures for these experiments were in accordance with ASTM E162-67 and the following parameters were computed as defined in that specification:

$$F_S\text{: flame-spread factor} = 1 + \frac{1}{t_4} + \frac{1}{6_4 - t_3} + \ldots .$$

where $t_3 \ldots t_6$ = time from initial specimen exposure until arrival of flame front at positions 3 . . . 6 . . . etc.

$$Q\text{: heat evolution factor} = 0.1\ T/B$$

where T — Obsesved maximum stack temperature rise over that obserwd with asbestos-cement board.

B — 0.836 = a constant for radiant panel apparatus used for tests.

$$I_S\text{: flame-spread index} = (F_S)(Q)$$

Results in TABLE 3 indicate a flame-spread index of 79 for unprotected GRP pipe specimens based on measurements averaged from Tests 2 and 3. The lower flame-spread index of 52 measured in Test 1 may have been due to the wire mesh screen applied over the specimens, in this test only, to prevent antipated Pipe fall-away during the experiment. The screen proved unnecessary since the specimens maintained sufficient integrity to prevent fall-away during their exposure of approximately ten minutes duration. Results of Tests 4, 5, and 7 show that the flame-spread index of 79 for unprotected GRP specimens could be reduced to an acceptable shipboard level of 25 or less with the addition of intumescent epoxy paint (approximately 10 roils), mastic coating compound (approximately 1/32 inch), and aluminized ceramic insulation (approximately 1/2 inch). The surface flammability level of 25 or less is below the limit of 30, as specified in MIL-P-0015280F(SHIPS) of 30 May 1973 for plastic foam materials now used for piping insulation aboard NAVY surface ships, and is within the more widely accepted criteria [4] used with ASTM E162-67 of $I_S = 25$ for shipboard applications. In Test 8, the pipe sections were covered with 1/2 inch of aluminized ceramic insulation which was coated with intumescent epoxy paint. The resulting flame-spread index of 92 demonstrates how the performance of intumescent epoxy paint, in terms of surface flammability. is a strong function of the substrate to which it is applied. When the paint was applied directly to the pipe specimen, it reduced surface flammability from 69 to 25, but when 1/2 inch of insulation (with I_S = O) was between the pipe and paint, the flame-spread index increased to 92. In Tests 7 and 8, it was necessary to test *two,* instead of the usual three, 110° sections of GRP pipe due to the additional thickness of the protective felt insulation and fixed dimensions of the steel mounting frame.

Smoke Density and Toxicity

Tests for smoke production and toxicity of gaseous products of decomposition were conducted with specimens of GRP piping using the smoke density chamber developed by the National Bureau of Standards (NBS) and commercial calorimetric gas detector tubes. There is a complete description of the smoke density chamber test by LEE [5], and a brief description of this method is taken from HILADO [3] as follows:

> The smoke test . . . employs a completely closed cabinet, measuring 3-feet wide, 3-feet high, and 2-feet deep. in which a specimen 3-inches square is supported in a frame such that a surface area 2-9/16-inches square is exposed to heat under either flaming or non-flaming (smoldering) conditions. The heat source is a circular foil radiometer adjusted to give a heat flux of 2.5 watts per square centimeter at the specimen surface. The photometer path for measuring light absorption is vertical, to minimize measurement differences due to smoke stratification which could occur with a horizontal photometer path at a fixed height. and the full 3-foot height of the

TABLE 3
SURFACE FLAMMABILITY TESTS WITH GLASS-REINFORCED PLASTIC PIPE SPECIMENS

Test	Description	Protective Measure	Flame Spread Factor (F_S)	Heat Evolution Factor (Q)	Flame Spread Index (I_S)[1]	Observations
1[2]	Three 110° Sections of 2-inch GRP pipe	None	3.28	15.8	52[2]	Some smoke with particulate, phenolic odor; some ablation
2	↓	↓	4.12	20.2	83	↓
3	↓	↓	3.93	19.1	75	↓
4	↓	Intumescent Epoxy Paint	4.60	5.5	25	Epoxy odor; some smoke, GRP pipe burning after 4.8 minutes into test
5	↓	Mastic Coating	2.14	10.4	22	Pipe resin seeped through cracks in protective coating; some smoke
6	↓	Intumescent Mastic Tape	3.12	19.1	60	Heavy smoke; GRP pipe exposed after 2.5 minutes
7	Two 110° Sections of 2-inch GRP pipe	1/2-inch aluminized ceramic insulation	1.0	0	0	GRP pipe in excellent condition after test; aluminum film remained on insulation
8	↓	1/2-inch aluminum ceramic insulation plus intumescent epoxy paint	24.2	3.8	92	Moderate smoke; extremely thick (1.5 - 2 inches) char; GRP pipe in excellent condition after test

(1) $(I_S)_{max}$ = 30 per MIL-P-0015280F(SHIPS).

(2) Pipe covered with wire mesh for this test only.

chamber is used to provide an overall average for the entire chamber. Smoke measurements are expressed in terms of specific optical density, which represents the optical density measured over unit path length within a chamber of unit volume produced from a specimen of unit surface area; since this value is dimensionless, it provides the advantage of presenting smoke density independent of chamber volume, specimen size, or photometer path length, provided a consistent dimensional system is used."

Results of the NBS smoke chamber experiments are summarized in TABLE 4.

Measurements averaged for Tests 1,2, and 3 shows maximum specific optical density of 286 under flaming conditions for *unprotected* GRP pipe specimens. The addition of intumescent epoxy paint in Test 4 reduced the smoke density level to 210. This reduced level is considered low relative to many plastic materials

TABLE 4
NBS SMOKE CHAMBER TESTS

Test	Sample Description	Protective Measure	Max. Specific Optical Density (Flaming)[1]
	GRP Pipe Specimens		
1	3- x 3- x 0.110-inch flat GRP specimen made from preimpregnated tape	None	251
2		None	328
3		None	278
4		Intumescent epoxy paint (Code B)	210
	Various Plastic Materials[2]		
1	3- x 3- x 0.125 inch PVC	None	525
2	3- x 3- x 0.156-inch polyester, glass-reinforced	None	395
3		Flame-retardant additives	618

(1) Maximum specific optical density (flaming) = 250 per MIL-P-0015280F(SHIPS).

(2) As reported by HILADO [3]

currently in shipboard service. For example, as shown in TABLE 4, polyvinyl chloride has a smoke density rating of approximately 525 which is 2 1/2 times that of GRP protected with intumescent paint. The smoke density level of 210 is below the limit of 250 specified, in MIL.P-0015280F(SHIPS) of 30 May 1973, for plastic foam materials used for piping insulation aboard surface ships.

Hazardous Gas Analysis

Gases generated during the smoke chamber tests with GRP specimens were analyzed with a Scott-Draeger multigas detector. This system consists of a small hand pump and calorimetric detector tubes which are calibrated to indicate the presence and concentration of a particular toxic gas by a color change which progressively increases in length as the gas concentration increases. A laboratory report supplied by the GRP resin manufacturer listing thermal decomposition products aided in the selection of potentially toxic gases to be analyzed. The concentrations of *nine* gases including CC, CO_2, $COCI_2$, HCI, HCn, HF, NH_3, NO_2. and SO_2 were measured and the results are shown in TABLE 5. Measured concentrations of the various gases were compared to personnel exposure limits established in BUMED INSTRUCTION 6270.3F (Personnel Exposure Limit Values for Health Hazardous Air Contaminants) of 15 August 1972. The 8-hour exposure limit value is defined in this INSTRUCTION as: "that concentration of health hazardous air contaminants to which all workers can be exposed for daily periods of 8 hours, 5 days a week, without adverse effects." Comparison of the measured gas concentrations to the 8-hour limits shows that for all gases except Carbon Dioxide the concentrations emitted from the GRP specimens were less than the 8-hour limit. With some gases, such as Carbon Dioxide, BUMED INSTRUCTION 6270.3F also allows computation of an equivalent concentration limit for exposure periods of less than 8 hours.

TABLE 5

HAZARDOUS GAS ANALYSIS
FOR GRP PIPE SPECIMENS

Hazardous Gas	8-Hour Personnel Exposure Limit* (ppm)	4-Hour Equivalent Personnel Exposure Limit* (ppm)	Measured Gas Concentration From GRP Specification (ppm)
CO	50		5
CO_2	5,00	10,000	10,000
$COCL_2$		—	0
HCl	5	5	4
HCn	10	—	4
HF	—		0
NH,	50	—	0
NO_2	5		0.3
SO_2	5	—	0

* BUMED INSTRUCTION 6270.3F of 15 August 1972.

Based on the BUMED formula, the 4-hour exposure limit for CO_2 is 10,000ppm or simply double the 8-hour limit. The measured concentration of CO_2 for the GRP specimen was 10,000ppm and corresponds to the 4-hour limit. Therefore, the concentration of gases generated from GRP piping in a shipboard tire situation would not be considered dangerous for personnel exposures of up to 4-hours duration. The general conclusion from this analysis is that gaseous products of decomposition contributed by GRP piping would not seriously affect personnel escaping from or engaged in fighting a shipboard fire. Work is currently underway to determine the effects of intumescent coatings on smoke toxicity.

Flowing Water Experiments

Simulated shipboard fire tests were conducted under flowing water conditions on GRP pipe along with conventional metallic piping materials represented by 90/10 copper-nickel and aluminum alloy 6063-T6 for comparison. Each experiment was conducted with a single test pipe filled completely with flowing water and

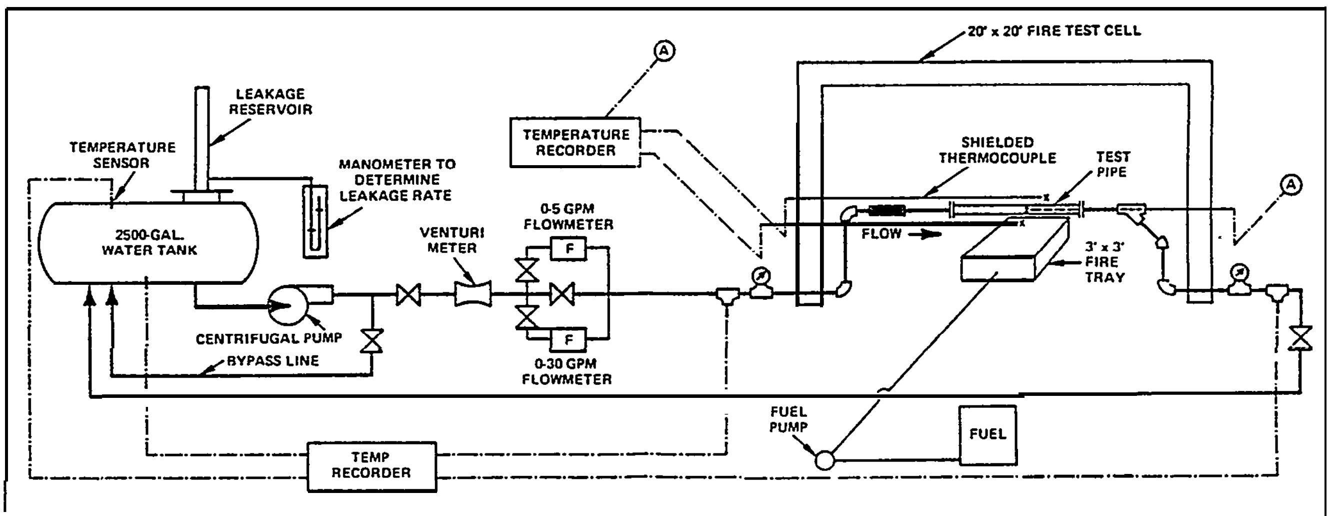

Figure 8. Experimental Facility for FIowing and Stagnant Water Fire Tests.

pressurized to 110 ± 10psig during the entire test. The fire test facility used for both flowing and stagnant water experiments is shown schematically in Figure 8. Freshwater from a 2,500-gallon storage tank was circulated through the system by a 40-horsepower centrifugal pump rated at 300gpm.

The tire test cell consisted of a galvanized steel hut, approximately 20-feet long, 20-feet wide, and 9-feel high, equipped with smoke ventilators and inner walls of ceramic felt insulation. Because of the long duration (up to 60 minutes) of each flowing and stagnant water test and the undesirable quantities of heavy smoke generated by fuels, such as gasoline, kerosene, diesel oil, and JP-5, it was necessary to find a much cleaner burning fuel. After comparing the relative amounts of smoke generated by various hydrocarbon fuels in small **fires, industrial grade hexane (C_6H_{14}) was selected as a** clean-burning, readily available fuel for the fire tests.

The test pipe center line was located approximately ***three*** feet above the fuel level in the fire tray. In all of the flowing water fire tests, the test pipes were supported by steel clamps on both sides of the fire tray. The unsupported span length above the fire was 44 inches, simulating anticipated shipboard support spacing. Chromel-alumel (Type K) thermocouples, encased in 1/4-inch diameter inconel sheaths approximately 10-feet long, measured flame temperatures on both sides of the test pipes at locations centered above the fire tray. Flame temperatures were continuously recorded during each tire test.

Detection of failure in test pipes in both flowing and stagnant water experiments was achieved by continuously monitoring the water head or level in a leakage reservoir installed above the 2,500-gallon tank, as shown in Figure 8. The entire circulating system was sealed except for the top of the reservoir which was open to the atmosphere. Small leaks occurring in a test pipe caused the water level in the leakage reservoir to drop. The resulting head loss was detected with a mercury manometer measuring static pressure at the base of the reservoir. The 2,500-gallon water storage tank was of sufficient capacity to maintain the temperature of water **entering the test pipe nearly constant (within 5°F)** during an entire 60-minute fire, thus simulating conditions expected in a slipboard seawater cooliig system constantly drawing cold water from the ocean. Although temperature changes in the storage tank were small, it was necessary to measure them accurately to account for growth of the control volume due to thermal expansion of the 2,500 gallons of water. Therefore, calibrated thermistors sensed water temperature at the top and bottom of the storage tank and measurements were continuously recorded on an oscillograph during each fire.

The majority of flowing water fire tests were conducted with low velocity laminar flow (0.1 ft/sec) in 2-inch-diameter pipes to develop conditions considered more severe than those expected in a shipboard piping system operating at normal design flow velocities. Typical results of flowing water tests with 2-inch-

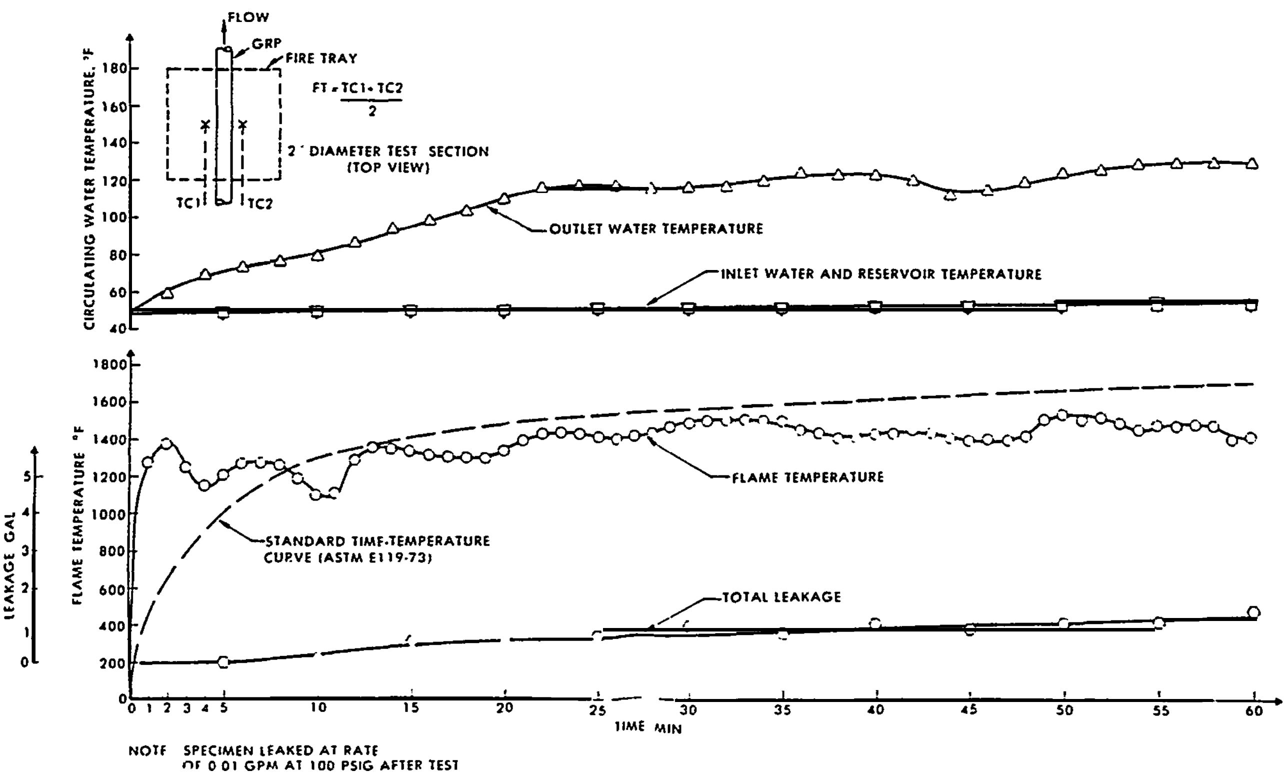

Figure 9. Flowing Water Fire Teat with 2-inch Diameter GRP Pipe (Laminar Flow).

diameter GRP pipe are shown in Figure 9. Flame temperatures were determined by averaging readings of thermocouples on both sides of the test pipes at locations centered above the fire tray. Flame temperatures were compared to the standard ASTM El19-73 Time/ Temperature Curve shown as a dashed line in Figure 9.

Unprotected Schedule 10 aluminum alloy 6063-T6 survived a l-hour test under conditions of laminar flow (1.2gpm) and I00psig minimum internal pressure with no leakage. Under similar conditions, an *unprotected* GRP test section leaked at *a* rate of *0.01gpm* after a l-hour fire exposure, as shown in Figure 9. This leakage rate is negligible considering that a 2-inch-diameter pipe will pass 122gpm at 10ft/sec. With the addition of approximately 10 roils of intumescent epoxy paint, a GRP test section survived a 30-minute fire with no detectable leakage during the fire, and a leakage rate of only 0.0005gpm at 100psig after the test. Under low velocity turbulent flow conditions (24.4gpm), the GRP test section survived a 30-minute fire with no detectable leakage. Tests conducted with a Class 200, 90/10 copper-nickel pipe assembly, including a silver-brazed bronze coupling, showed no leakage in the pipe or joints after 30 minutes under laminar flow conditions (1.2gpm).

Stagnant Water Experiments

Full-scale tire tests were conducted under stagnant water conditions with the fire test facility and equipment previously described for the flowing water experiments. During the stagnant water tests the throttling valve downstream of the tire test section was closed, and water from the pump was continuously diverted back to the reservoir via the bypass line shown in Figure 8. The test section was completely filled with stagnant water (air was vented from the test section before each tire) at pump discharge pressure, and leaks occurring in the test pipes were measured by the failure-detection scheme previously described. Since the stagnant water condition represents the worst case in a fire with water-filled pipes, it was decided that both 1- and 2-inch-diameter GRP pipe assemblies with molded and filament-wound fittings and adhesive-bonded joints would be tested in this state. Tests also were conducted with 2-inch-diameter 90/10 copper-nickel piping with a silver-brazed bronze coupling, and with 2-inch-diameter aluminum *alloy* piping with and without a welded aluminum coupling. The stagnant water fire tests are considered extremely important in relation to selection of piping materials for water circulating systems. Although pipes which serve as headers in a shipboard water distribution system may be continuously filled with flowing water during normal operations, some of the piping branching off and pressurized by the headers could simultaneously be in a stagnant water state. Therefore, the integrity of a circulating system can be threatened by nonisolated branch lines filled with stagnant water.

Results of the stagnant water fire tests with unprotected Schedule 10 aluminum alloy showed catastrophic failure within 9 minute after fire ignition. Temperature data showed that water inside the aluminum pipe evaporated to steam within 2-1/2 minutes after ignition due to the high thermal conductivity of the pipe wall. Although pressure in the test section remained constant after it was filled with steam, the pipe-wall temperature climbed toward the melting point of the alloy (llOO°F-1210°F), with associated reduction in ultimate strength capability, until the wall ruptured and the test was terminated. The experiment was repeated with another 2-inch diameter section of aluminum alloy piping containing a welded coupling, and results showed catastrophic failure after approximately 12 minutes. Results of a stagnant water fire test conducted with a 2-inch diameter 90/10 copper-nickel pipe containing a silver-brazed bronze coupling showed that leakage was detected at the silver-brazed joint after 15-1/2 minutes, and physical separation of the pipe from the coupling was observed after 18 minutes. As in the case of aluminum, water inside the copper-nickel pipe was evaporated to steam which allowed temperature of the assembly to climb toward the melting point of the silver-brazing alloy with subsequent joint failure.

Results of a 30-minute fire test involving 2-inch GRP piping with molded GRP fittings (two 90° elbows, a tee, and a threaded reducer bushing) and adhesive-bonded joints, are presented in Figure 10. Results show that the assemb[y reached a quasi-steady-state condition after approximately 10 minutes as indicated by no further increase in leakage rate and constant internal water temperature. After the l/2-hour fire exposure, the assembly was repressurized to 1601b/in^2, and the total leakage rate equaled lgpm. Although the pipe. fittings, and joints were charred from the fire, they appeared in structurally sound condition after the test. There were minor leaks at two of the bonded joints and at a molded seam in one of the elbows, but there were no signs of separation or back-out in any of the seven bonded joints in the assembly. To ensure that these test results were representative of anticipated ship-board performance, the entire test was repeated with 2-inch diameter GRP pipe and molded fittings which, in this experiment, included a flange, a tee, an elbow, and a molded plug. In this second test, the total fire exposure was approximately 45 minutes at 1601b/in^2. Assembly leakage after the fire equaled 0.3gpm, and again there were no signs of joint separation. A stagnant water fire test also was conducted with l-inch GRP piping and molded fittings (including a 90° elbow, a tee, a flange, and a blind flange) after heat transfer studies showed that 1-inch GRP pipe was the most sensitive to fire damage from a thermodynamic standpoint. Test results showed that the l-inch assembly reached a quasi-steady-state condition after 10 to 15 minutes and that it survived the 30-minute fire without joint separation or fitting failure.

In the final series of stagnant water experiments, tire tests were conducted with 2-inch diameter GRP pipe assemblies containing in-line filament-wound GRP fittings with bonded joints. The filament-wound fittings are made with basically the same materials and tech-

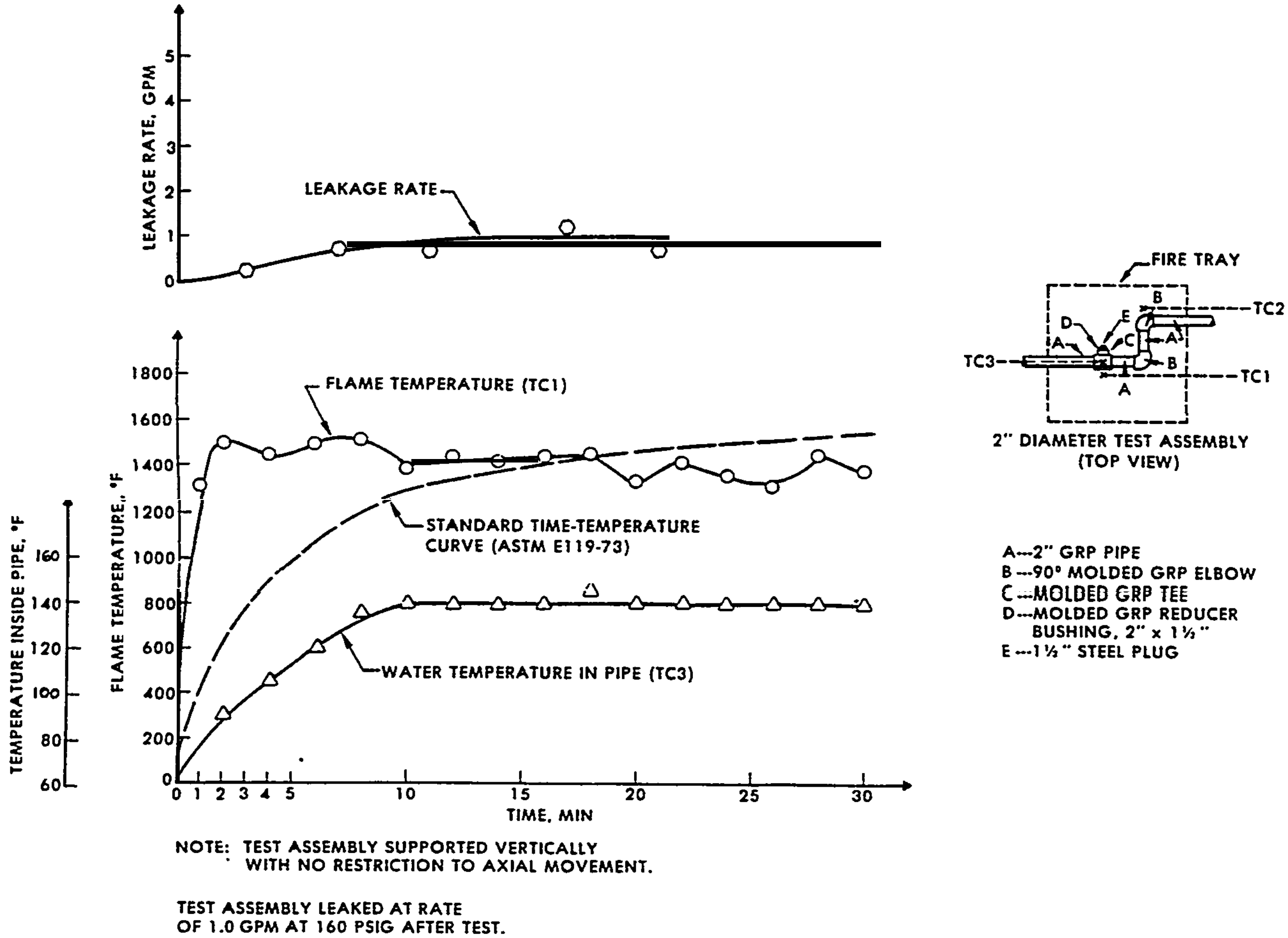

Figure 10. Stagnant Water Fire Teat with *2-inch Diameter GRP Pipe with* Molded Fittings and Bonded Joints.

niques used in the pipe winding process, but generally they have much thinner walls than the molded fittings previously tested. A filament-wound sleeve coupling and a filament-wound threaded adapter were tested simultaneously in a stagnant water assembly at 1601b/in^2. Results showed that joint separation occurred at the threaded adapter 3 minutes and 20 seconds after tire ignition. The minimum thickness of the threaded adapter was 0.094 inch. Apparently the thickness of the filament-wound fitting was insufficient to provide the thermal insulation required to protect the adhesive-bonded joint. Two additional stagnant water tests were conducted with 2-inch filament-wound sleeve couplings at 1001b/in^2, and in both cases failure occurred as joint separation at the coupling. Based on these results and a survey of the minimum wall thickness of both molded and in-line filament-wound fittings as they are currently produced by one manufacturer in the 1 through 6-inch size range, it was concluded that sleeve couplings, threaded adapters, and 45° lateral fittings are of insufficient thickness to protect bonded GRP joints in a stagnant water fire situation.

An additional implication that can be drawn from the fire test relates to shipboard fire systems conveying combustible liquids and gasses. Due to the failure mechanism of GRP pipe in a fire situation, which involves a gradual burning away of epoxy resin, leaving layers of filament wound fiberglass through which mild leakage can occur, unprotected GRP piping should not be used in fuel, hydraulic oil, lubricating oil, or other systems carrying combustible liquids or gasses. Additionally. due to the electrical insulating properties of the piping material. its application with nonconducting combustible fluids requires special design considerations to prevent the possibility of static electrical charge build-up.

Dry-Pipe Experiments

Full-scale tests were conducted with 1- and 2-inch diameter GRP pipe and fittings with and without various fire protective measures under dry-pipe conditions. In these experiments, the pipes were filled with air and sealed at both ends. Failure was determined by monitoring and recording internal air pressure during each test. Three pipe sections were generally tested simultaneously by this arrangement. Relief valves connected to each test assembly limited pressure rise to

approximately 20psig to prevent dangerous explosions at failure. Encased thermocouples measured flame temperatures on both sides of each specimen at locations centered above the fire tray. Heavy-walled open-end steel pipes at each end of the pipe rack acted as spacers, providing an even air gap around each test section. Transducers sensed the pressure in each pipe section and provided electrical signals to an oscillograph for continuous pressure recording during each fire test.

The performance of 2-inch nominal size GRP, aluminum alloy, and copper-nickel piping was measured under dry-pipe conditions. Results showed that: the Schedule 10 aluminum alloy (6063-T6) piping failed catastrophically within two minutes after ignition; the GRP pipe failed at approximately the same time, but failure occurred slowly as the resin gradually burned away leaving layers of glass fiber windings; and the copper-nickel (70-30) pipe specimen survived the entire nine minute test with no apparent damage. However, when a silver-brazed coupling was tested, with the copper-nickel pipe, failure occurred at the joint after four minutes of exposure.

Additional dry-pipe experiments were conducted to determine the performance of 1- and 2-inch diameter GRP pipe with filament-wound and molded fittings and **to evaluate the effectiveness of various candidate fire-**protection measures. The dry-pipe state is considered the most severe conditioning a piping system could be subjected to, and therefore provides the most desirable situation for evaluation of fire-protective measures. The dry-pipe experiments are summarized in Figure 11 as bar graphs representing time to failure for each GRP pipe section evaluated.

Pipe Insulation

The most effective lightweight protective measure tested was ceramic felt insulation in the form of an aluminized felt batting. The ceramic felt insulation (41b/ft^3) in 1/4-, 1/2-, and l-inch thicknesses provided

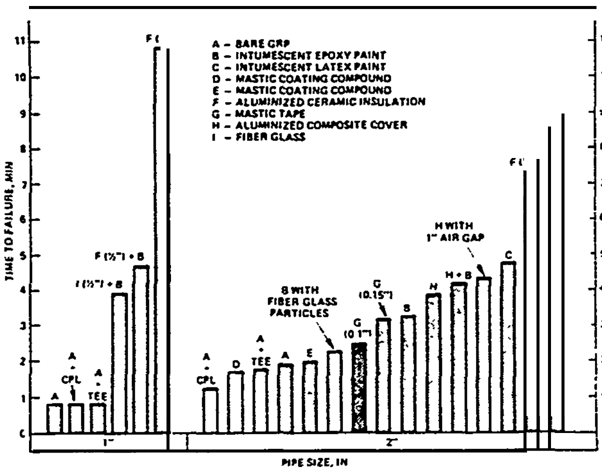

Figure 11. Fire Performance of Various Protective Measures with GRP Pipe.

from 4 to 10 minutes of protection with 1- and 2-inch diameter GRP test sections. This insulation was unaffected by the fire exposure, and as shown by the radiant panel experiments, has a surface flammability rating of zero. In small-scale tests conducted at the National Bureau of Standards [6] the ceramic felt remained dimensionally stable during the test, did not smoke to any extent, and had low toxic gas *emissions. The* weight of GRP piping covered with this insulation system (including a protective aluminized fiber-glass cloth ***cover*** weighing 21 ounces per square yard, aluminum-backed sealing tape, and lightweight stainless-steel straps) in thickness up to and including ***one*** inch is approximately equal to or less than the weight of bare Schedule 10 aluminum alloy pipe over the entire 1- through 6-inch size range. The material costs for GRP piping employing this insulation system are 38% of bare 90/10 copper-nickel (Class 200) for the 5-inch size, 77% for the 3-inch size, and 175% for l-inch diameter lines.

MECHANICAL PROPERTIES

Experiments were conducted with 1-, 3-, and 6-inch diameter GRP pipe *assemblies* to measure mechanical properties (elastic moduli and Poisson's ratio) of the pipe wall in the axial, hoop, and 45° directions. Knowledge of these properties was required to convert rosette strain-gage measurements from cyclic fatigue tests to corresponding stress levels. The pipe specimens were subjected to tension, compression, bending, torsion, and internal pressure. The test assemblies were straight sections of GRP pipe flanged at both ends and having an overall length of three feet. Rectangular rosette-type strain gages were mounted in pairs, 180° apart circumferentially, five-inches above and below the center of each test assembly. The gages were connected through "switch-and-balance" units to Budd strain indicators. The base of the test section was bolted to a rigid steel frame, and tensile, compressive, and bending loads were applied in turn to the top of the assembly with a turnbuckle arrangement. Forces developed in each turnbuckle leg were measured by calibrated load cells and were transmitted through pin joints and ***a*** 24-inch moment arm to the top of the test section. The turnbuckle legs could be swiveled 90° into the horizontal plane so that torsional loads could be applied to the test section. The turnbuckle legs and moment arm could also be removed for pressure test with the GRP assemblies.

The results of experiments to determine elastic **moduli and Poisson's ratios at room temperature (70°F)** appear in TABLES 6 and 7 for the 1-, 3-, and 6-inch diameter test sections. Values listed in these tables generally represent the average of several measurements taken over a range of loading conditions. For example, the 6-inch diameter GRP pipe was tested under tensile and compressive loads of 2,000, 4,000, and 6,000 pounds. Over this loading range, the tensile modulus varied from 1.85 x 10^6 *to* 1.88 x 10^6, and the ***compressive*** modulus ranged from 1.80 x 10^6 to 2.05 x 10^6 indicating that results were approximately linear. Com-

parisons of the measured properties (in TABLES 6 and 7) show good agreement between values for the 1- and 6-inch diameter pipes. This is explained by the fact that the 1- and 6-inch test pipes were manufactured in a wet-bath individual-stand winding process, while pre-impregnated tape was used in the production process for 2-, 3- and 4-inch sizes. To ensure that these differences in the production process explained the variation in mechanical properties obtained with the 3-inch pipes, several additional tests were conducted with a 2-inch specimen. As suspected, the results for the 2-inch pipe were in relatively good agreement with the 3-inch properties, showing that the property variations were due to the production processes. [$E_T = 1.4 \times 10^6$; $E_H = 2.5 \times 10^6$; (μ_H) axial tension = 0.43; (μ_{AX}) hydrodynamic pressure = 0.75; and ($\mu_{45°}$) axial tension = 0.219] (It is understood that the production process for 2-, 3-, and 4-inch diameter piping has been modified subsequent to these experiments.)

maining two pipe assemblies were used as control sections.

The test assemblies were bolted into a simple tension apparatus. A worm-gear jack applied tensile forces to the test assemblies in 250-pound increments as measured by a calibrated load cell. The tension was increased until initial failure was detected by water leakage from the test assemblies which were pressurized to approximately 10lb/in^2.

The results of the 2-inch GRP axial tension tests are summarized in TABLE 8 which shows that a notch in the pipe up to **50%** of the wall thickness resulted in only a 7% decrease in the tensile load causing failure in the pipe. TABLE 8 also shows that no reduction in tensile strength was found on the GRP pipe section with the scarred exterior. These results are explained by the relatively heavy layer of epoxy resin on the outside of the pipe wall which protects internal load-bearing glass filaments from exterior damage. One other result of the

TABLE 6

EXPERIMENTAL ELASTIC MODULI FOR GRP PIPING AT ROOM TEMPERATURE

Nominal Pipe Size (in.)	Modulus of Elasticity: Axial Tensile $E_T \times 10^{-6}$ (lb/in²)	Hoop $E_H \times 10^{-6}$ (lb/in²)	Compressive $E_c \times 10^{-6}$ (lb/in²)	Bending $E_b \times 10^{-6}$ (lb/in²)
1(1)	2.1	3.3	—	—
3(2)	1.4	2.2	1.6	1.4
6(1)	1.9	3.4	1.9	1.8

(1) Constructed using wet winding process.
(2) Constructed using preimpregnated-tape winding techniques.

TABLE 7

EXPERIMENTAL POISSON'S RATIOS FOR GRP PIPING AT ROOM TEMPERATURE

Nominal Pipe Size, (in.)	μ_{hoop} For Axial Tension	μ_{hoop} For Axial Compression	μ_{axial} For Hydrostatic Pressure	μ_{45} For Axial Tension	μ_{45} For Axial Compression
1(1)	0.33	—	0.51	—	—
3(2)	0.42	0.50	0.68	0.29	0.28
6(1)	0.33	0.44	0.77	0.36	0.31

(1) Constructed using wet winding process.
(2) Constructed using preimpregnated-tape winding techniques.

Experiments were also conducted with 2-inch diameter GRP pipe assemblies to determine the effect of notching and scarring the pipe wall on the ultimate tensile strength of the pipe. The six test sections used were straight pipe sections of GRP flanged at both ends with an overall length of approximately 22 inches. Three of the test pipes each had a 60-degree notch with a 0.015-inch root radius machined around its circumference to a depth corresponding to 20%, 35%, and 50% of the pipewall thickness, respectively. One test assembly was deliberately damaged by repeated twisting in a chain vise to scar the exterior of the pipe. The re-

axial tension test, as indicated by the failure locations, was that the pipe joints were shown to be comparable in strength to the GRP pipe in axial tension.

Cyclic Fatigue Characteristics

Investigations of the cyclic fatigue characteristi GRP piping were conducted with 1-, 3-, and 6-inch diameter assemblies representative of the smalle largest, and mean diameter GRP pipe being considered for application aboard advanced naval surface ship The objectives of these investigations were:

TABLE 8

AXIAL TENSION TEST FOR 2-INCH GRP PIPE

Test Assembly	Failure Load (lb)	Failure Location
Control pipe		
1	7,000	Lower section of pipe.
2	6,900	Bonded joint.
Notched pipe		
20(% of wall thickness)	7.250	At notch in pipe.
35(% of wall thickness)	6,750	Bonded joint.
50(% of wall thickness)	6.500	At notch in pipe.
Scarred pipe		
1	7,500	Center section of pipe.

• To develop an S-N Diagram on which STRESS TO

Low-Frequency Experiments

Cyclic fatigue investigations were conducted with low-frequency equipment to determine the characteristics of 1-, 3-, and 6-inch diameter GRP pipe, fittings. and joints under conditions of internal pressure and bending stress. Four l-inch, eight 3-inch, and two 6-inch pipe assemblies were tested with the apparatus shown in Figure 12. Each pipe assembly included: molded GRP flanges, a filament-wound sleeve coupling, and a molded GRP elbow. The assemblies were deflected to either side of a neutral position for completed stress reversal. Each assembly was filled with freshwater, and internal pressurization from atmospheric to maximum rated pressure was synchronized with deflection, so that maximum rated pressure was applied at both the extreme up and down positions. The cycling rate was approximately 5c/m. Peak-to-peak deflection of the l-inch diameter assemblies ranged from 1-3/8 inches to

± 1/4 degree of manufacturer's recom-

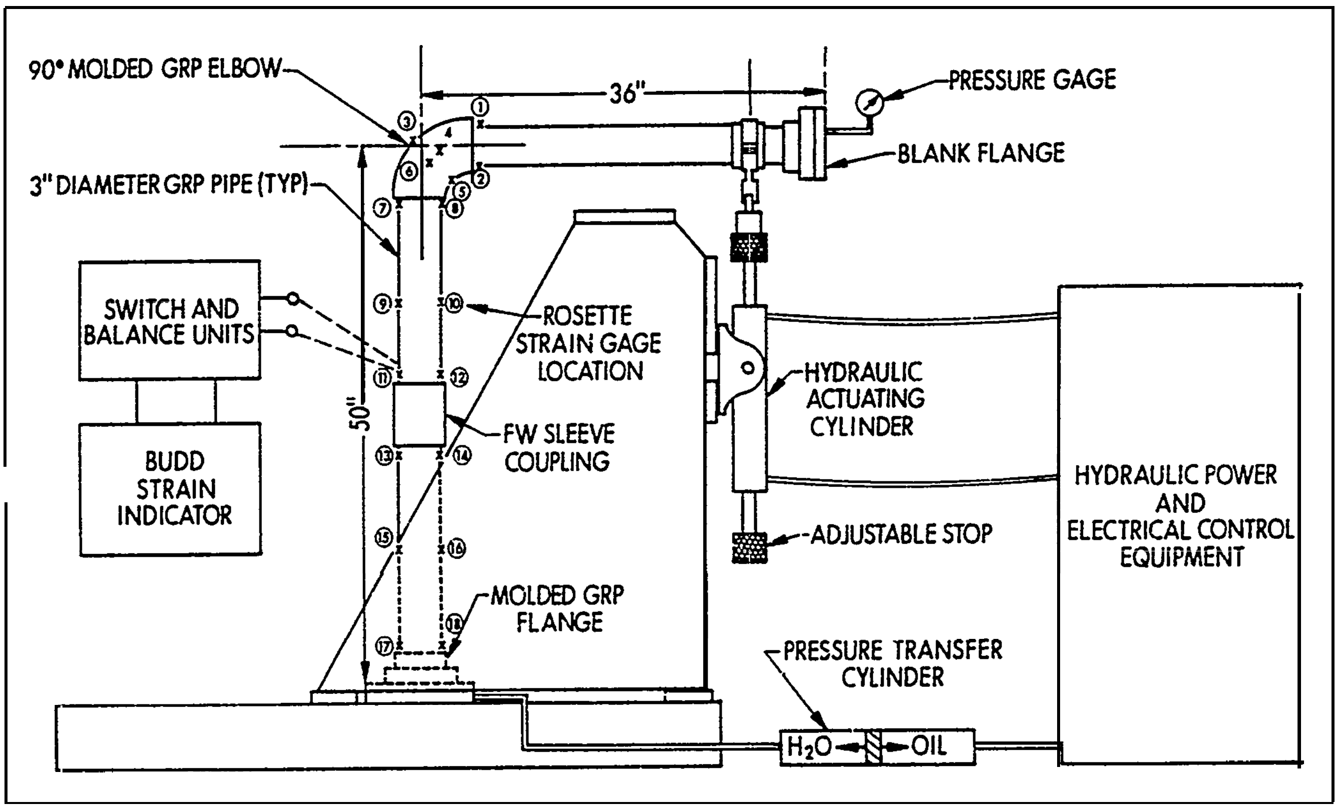

Figure 12. Low-Frequency Fatigue Facility for GRP piping.

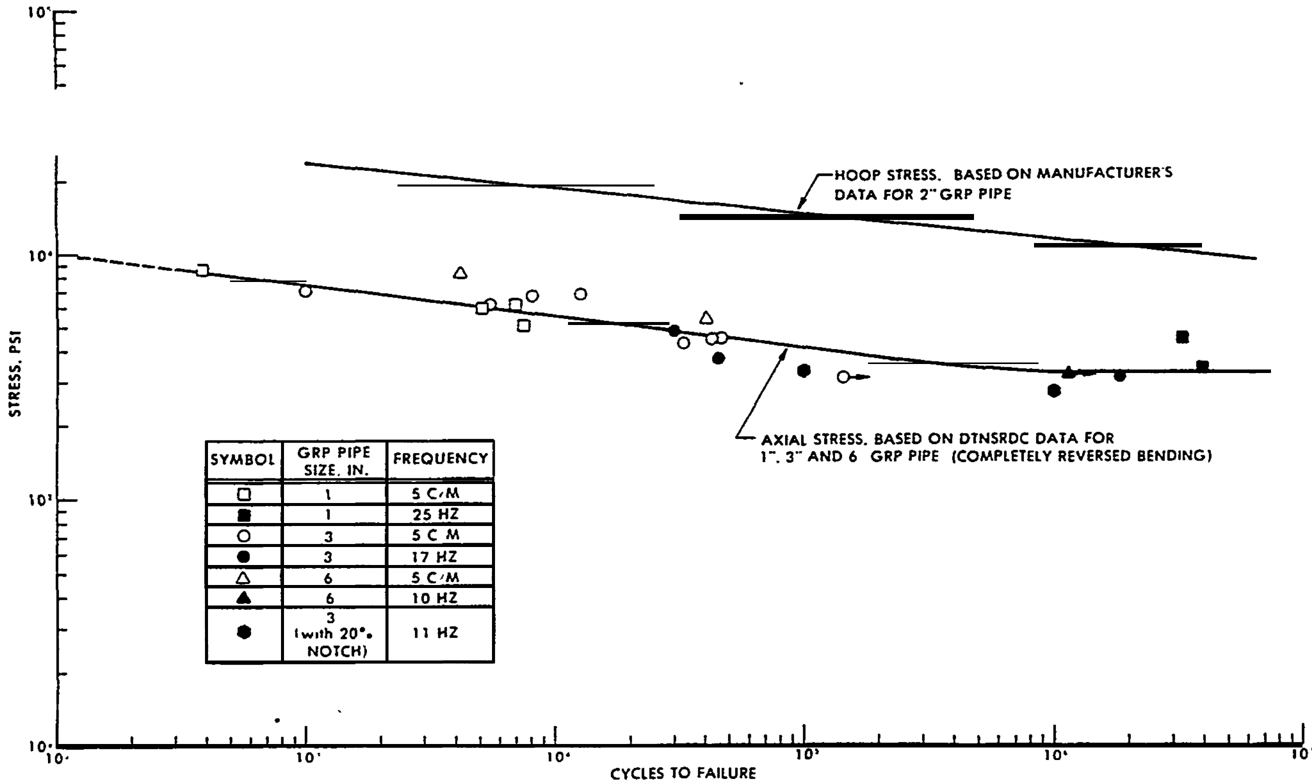

Figure 13. Cyclic Fatigue Characteristics of GRP Pipe Test Assemblies.

axial, and 45° strain. The gages were connected through switch and balance units to Budd strain indicators or automatic Gilmore strain recorders.

The assemblies were automatically cycled, and *the smallest detectable leak (including weeping) constituted ,failure.* Results of these experiments are plotted in Figure 13 as the unshaded data points. Despite the large deflections to which the assemblies were subjected, all failures occurred as weeping in the pipe wall which is a relatively safe failure in any of the joints or fittings. Strain measurements on both molded and filament-wound GRP fittings indicated that they were operating at relatively low stress levels due to their rigidity compared to the piping. This is demonstrated in Figure 14 where principal stresses occurring in a typical 1-inch diameter fatigue assembly are plotted as a function of strain gage location. It should be mentioned that in all 14 assemblies there were no failures in any of the joints or fittings.

Failure occurred in the GRP pipe as small cracks, usually parallel to the fiber winding angle, which leaked when the assembly was at or close to maximum deflection. Normally when the assembly was returned to its neutral position, the leak would stop completely even when the assembly was fully pressurized. In most cases, leakage amounted to only a few drops, and all assemblies maintained internal pressure. To demonstrate this gradual mode of failure. the leakage rate from a 1-inch diameter low-frequency assembly, which failed after

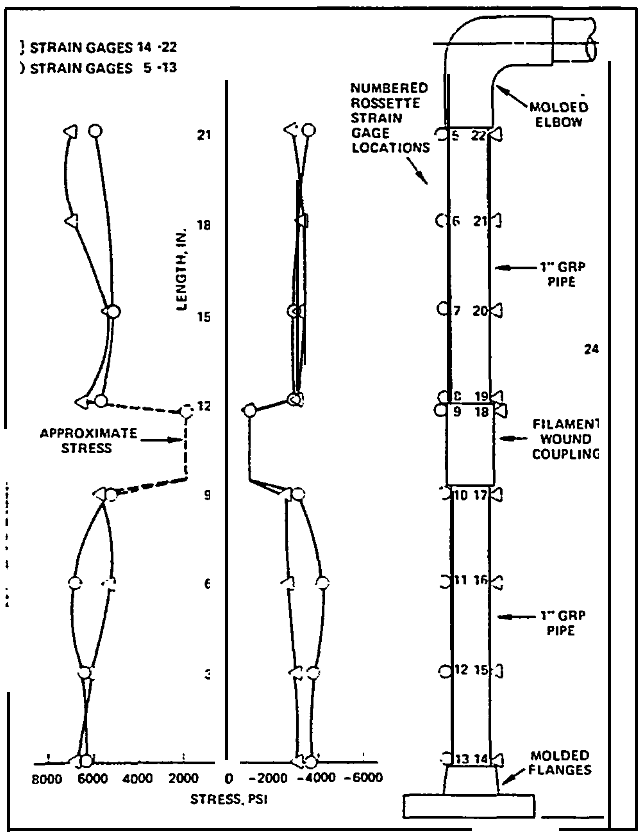

Figure 14. stress Distriiution Occurring in Typical l-inch Diameter Low-Frequency Fatigue Assembly.

1500 cycles under extreme deflections, was monitored during an additional 5,000 cycles at the same deflections and pressure. Results showed that the leakage rate increased very gradually during the additional cycling and had nearly leveled off at the extremely low rate of 0.05ml per minute after 6,500 cycles.

Principal stresses, plotted in Figure 13, occurring in the test pipes at maximum deflection were always in or very close to the axial direction. The stresses for maximum tension and compression were computed from rosette strain gage measurements at or near the location of failure by first determining the principal strains and their directions using the following equations from Petrisko [7]:

$$\epsilon_{\substack{max\\min}} = 1/2\,(\epsilon_1 + \epsilon_3) \pm 1/2\sqrt{(\epsilon_1 - \epsilon_3)^2 + \left[2\epsilon_2 - (\epsilon_1 + \epsilon_3)\right]^2}$$

$$\phi = 1/2\tan^{-1}\left[\frac{2\epsilon_2 - (\epsilon_1 + \epsilon_3)}{\epsilon_1 - \epsilon_3}\right]$$

where: $\epsilon_1, \epsilon_2, \epsilon_3$ = strain measurements from a 45°, three-gage, rectangular rosette.
ϕ = the angle from direction (1), counterclockwise to maximum strain or stress.

Principal stress could then be computed from the principal strains using

$$\sigma_A = \frac{E_A}{1 - \mu_A \mu_B}\left[\epsilon_A + \mu_A \epsilon_B\right]$$

and —

$$\sigma_B = \frac{E_B}{1 - \mu_B \mu_A}\left[\epsilon_B + \mu_B \epsilon_A\right]$$

where: ϵ_A = maximum strain.
ϵ_B = minimum strain.
E_A = modulus of elasticity in the direction of maximum strain.
E_B = modulus of elasticity in the direction of minimum strain.
μ_A = Poisson's ratio in the direction of maximum strain.
μ_B = Poisson's ratio in the direction of minimum strain.

Generally, since the value of ϕ was small ($\phi \leq 5°$), E_A, E_B, μ_A, and μ_B could be closely approximated by properties of the pipe wall previously measured in the axial and hoop directions. The alternating stress (S_{alt}) to which the pipe wall was subjected could then be determined from:

$$S_{alt} = \frac{(\sigma_A)\text{ tension} + |\sigma_B|\text{ compression}}{2}$$

where: (σ_A) tension = maximum stress occurring with the pipe wall in tension.
$|\sigma_B|$ compression = absolute value of minimum stress occurring with the pipe wall in compression.

And the mean stress level (S_m) could be computed from:

$$S_m = (\sigma_A)\text{ tension} - S_{alt}$$

The equivalent stress, S_{eq}, defined as the alternating stress component which produces the same fatigue damage at zero mean stress as the actual alternating stress component (Salt), produced at the existing value of mean stress, can then be determined from the following formula:

$$S_{eq} = \frac{S_{alt}}{1 - \frac{S_m}{S_u}}$$

where: S_u = the ultimate axial strength of the pipe wall or 9,747 lb/in² at 75°F (ASTM D-2105-62T). The equivalent stress, S_{eq}, was then plotted against CYCLES to FAILURE for each low-frequency assembly tested to generate the S-N data from 0 to 100,000 cycles shown in Figure 13.

High-Frequency Experiments

Cyclic fatigue experiments were conducted with vibration apparatus and in various GRP pipe configurations to generate high-frequency fatigue data to 4.0 x 10^6 cycles. One 6-inch, six 3-inch and four 1-inch assemblies were tested in the frequency range from 10Hz to 2SHz (Figure 15). Each assembly was filled with freshwater and pressurized at its maximum rating (300psig for l-inch, 200psig for 3-inch, and l50psig for 6-inch sizes). Internal pressure was not cycled during these experiments. Alternating stress levels wre controlled by the geometry of the test configuration, the weight of a steel plate (25 to 100 pounds) supported by each assembly, and the vibration rate of the driving table which was held constant during each test. Failure was determined by the first visible leak or detectable loss in internal pressure. Axial and rosette-type strain gages were mounted at critical locations along the test pipes to determine operating stress. The gages were connected through a switch and balancing circuit to an oscillograph which recorded alternating strain measurements.

Results of the high-frequency experiments are plotted in Figure 13 as shaded data points. *All failures in the high-frequency assemblies occurred as gradual weeping in the pipe wall.* In all 11 assemblies there were no failures in any of the joints or fittings. The equivalent principal stresses (S_{eq}) for the high-frequency assemblies were always in or very close to the axial direction and were computed from:

$$S_{eq} = \frac{S_{alt}}{1 - \frac{S_m}{S_u}}$$

where: S_{alt} = the alternating axial stress computed as the product of the axial modulus of elasticity (E_T) and one half

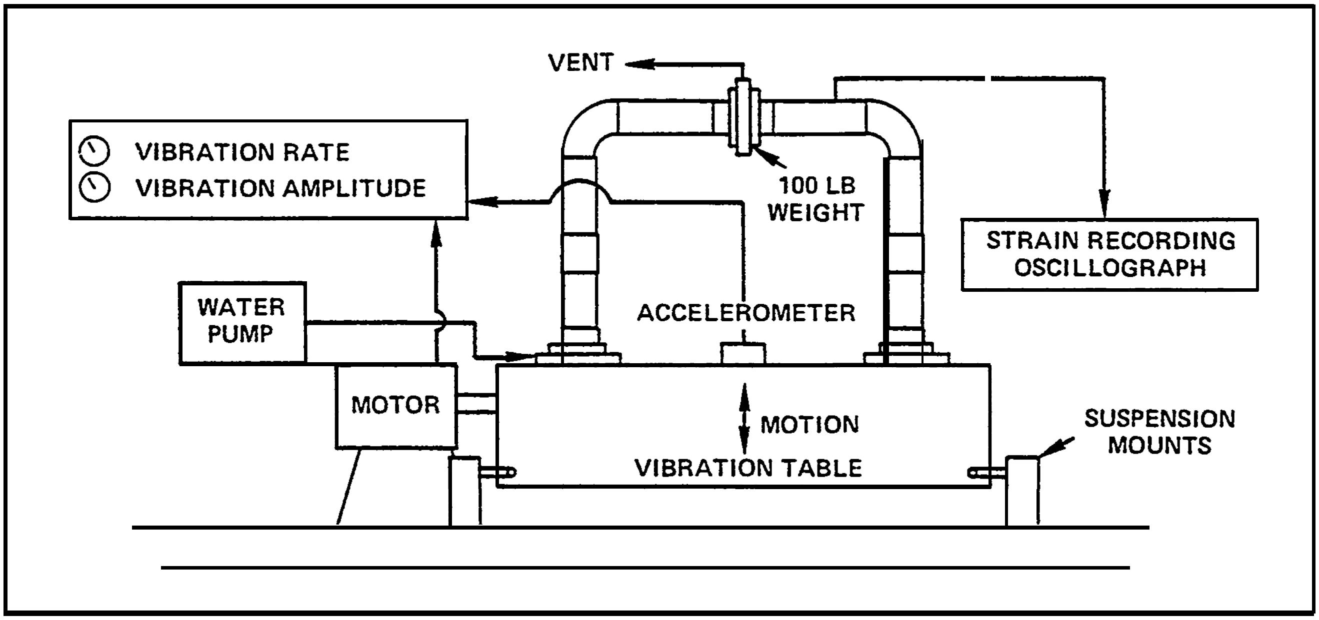

Figure 15. High-Frequency Fatigue Apparatus for 3-inch Diameter GRP Piping.

the maximum measured peak-to-peak axial strain.

S_m = the component of axial stress in the pipe wall due to constant internal pressure computed from: [Pr/2t]. where "P" equals internal pressure, 'r' equals the inside pipe radius. and "t" equals pipe wall thickness.

S_u = the ultimate axial strength of the pipe wall or 9.747 lb/in² at 75°F (ASTM D-2105-62T).

An indication of the effect of notches and severe external damage on the GRP pipe wall under high-frequency cyclic fatigue conditions is provided by the data in Figure 13 for two notched 3-inch diameter assemblies tested at 11 Hz. A 60-degree notch with a 0.015-inch root radius was cut into both test pipes around their circumference to a depth corresponding to 20% of their wall thickness. The assemblies were strain gaged. pressurized, and tested according to the procedure previously described. Failures occurred at approximately 10^5 and 10^6 cycles as slow leaks in the notches. Results indicate that the 20% reduction in wall thickness may have caused a 16% to 20% reduction in fatigue strength of the pipe wall. This interpretation of the data is inconclusive since it can be argued that the notched data points fell within the range of data scatter for the unnotched pipe specimens.

Support Spacing Ana!ysis

The spacing of pipe supports in shipboard systems with GRP piping can be determined as a function of allowable stress and deflection criteria. Factors that control the stress and deflection levels include: Pipe dimensions, Mechanical properties, Weight of the pipe and contained fluid. Internal pressure, Operating temperature. Thermal expansion effects, Concentrated loads due to external forces, Environmental vibration, Maximum accelerations to which the system will be subjected, and Type of pipe support.

Generally shipboard piping will be either concealed (in the overhead or beneath a deck) or exposed to crew traffic (in compartments and passageways). Larger diameter size (2-inches and above) exposed pipes should be able to support the weight of a sailor who may find it necessary to occasionally climb on the piping to reach other equipment. Therefore. the first criteria restricting pipe support spacing are stresses and deflections computed for various span lengths of GRP piping with concentrated loading between both simple and fixed supports. Computations were made for water-filled GRP pipes from 1 inch through 6 inches in diameter at temperatures of 25°F, 75°F, and 180°F with a concentrated load of 200 pounds at the center of each span. The computations were based on formulas developed for thin-walled pressure vessels and elastically stressed straight beams modified to account for variations in mechanical properties of the composite pipe wall in the axial and hoop directions [8]. Tensile strength properties and axial moduli of elasticity for GRP piping as a function of temperature were provided by the manufacturer. Using these properties and those summarized in TABLES 6 and 7, calculations, for both simple and fixed support, were made with the aid of a computer program using a maximum allowable deflection of *one* inch, a maximum stress criteria of one-half ultimate tensile strength, and an internal operating pressure of 150lbs/in². The program assumed an installation temperature of 75°F and included axial loading due to thermal expansion/contraction effects at maximum operating temperatures. When net axial loading on a pipe span was compressive due to expansion at higher operating temperatures, the program computed the minimum unsupported span length at which buckling

could occur. Results of the computations for simple and fixed supports were averaged to represent characteristics of a GRP pipe-hanger system which consisted of adjustable 360° clamps equipped with rubber liners of 60-durometer rating, in compliance with MIL-R-6855, to protect the GRP pipe surface from abrasive damage and to reduce vibration and sound transmission. Maximum unsupported span lengths were determined from both the stress and deflection criteria over the entire operating temperature range for one through six inch diameter GRP piping.

The next criterion restricting support spacing of GRP piping concerns environmental vibration. It is important to ensure that the fundamental natural frequency of the piping system will not be in the neighborhood of a forcing frequency of significant amplitude.

The natural frequency (fundamental mode) of a beam with uniform mass distribution, such as a water-filled GRP pipe. can be computed by using the following formula [9]:

$$f_n = \frac{\alpha}{L^2}\sqrt{\frac{EI}{w}}$$

where: f_n = the fundamental natural frequency, Hz.
α = a coefficient which varies with supporting conditions and mode.
L = length of pipe, ft.
E = modulus of elasticity. lb/in².
I = moment of inertia, in⁴.
w = weight per foot of pipe (including contents). lb/ft.

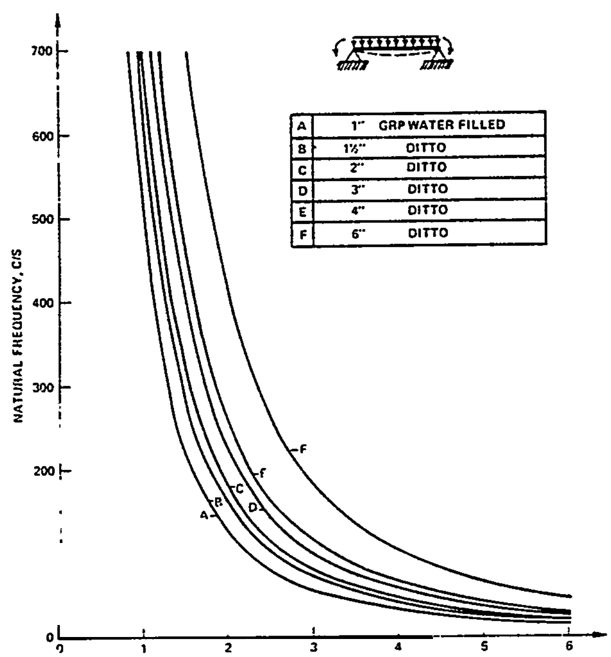

Figure 16. Natural Frequency (Fundamental Mode) of GRP Piping for Semi-Rigid Supports.

In the case of a pipe with both ends simply supported a equals 0.743 for the fundamental mode, and in the case of fixed supports at both ends a equals 1.69 for the fundamental mode. Since the recommended pipe supporting system includes rubber padding, and is considered semi-rigid, setting α equal to 1.22 represents the average of simple and fixed conditions. Using this average value of a and the above equation, the natural frequency of 1- through 6-inch-diameter GRP piping at 75°F for semi-rigid supports was computed as a function of unsupported span length. and the results are plotted in Figure 16. The natural frequency of GRP pipes operating at 180°F will be approximately 9% to 14% less than the room temperature values in Figure 16. and the natural frequency of GRP pipes operating at temperatures lower than 75°F will always be higher than those at room temperature.

The final criterion restricting support spacing requirements concerns maximum accelerations to which the piping could be subjected. and the capability of a water-filled system to operate continuously at stress levels below a safe endurance limit when exposed to these accelerations. The maximum bending stress occurring in a simply supported beam with uniform mass distribution. such as a water-filled GRP pipe. can be computed from:

$$(S_b)_{max} = \frac{Mc}{I} = \frac{(1/8\ w\ l^2)c}{I}$$

where: $(S_b)_{max}$ = maximum bending stress, lb/in².
M = maximum bending moment occurring at the center of a simply supported beam with uniform loading. in-lb.
c = outer radius of pipe. in.
I = moment of inertia, in⁴.
w = weight per foot of pipe (including contents). lb/in.
l = unsupported span length. in.

Since the piping will be subjected to accelerations transmitted through the ship structure. the bending stress will increase in direct proportion to the "g" loading. The S-N data presented in Figure 13 indicates a quasi fatigue or endurance limit in bending of approximately 3.0001b/in² for the GRP piping investigated. Applying a safety factor of 2 to account for material defects. installation or service damage, and other uncertainties. a design stress of 1.5001b/in2 can be used in the above equation to compute maximum spans at specified "g" loadings. These maximum span lengths will allow a water-filled GRP pipe to operate continuously for the design life of the ship under the specified accelerations.

The three criteria discussed in the foregoing paragraphs can be used to determine support spacing requirements for a specified GRP piping system. Since the criteria can vary so greatly as a function of ship type and system. specific recommendations for maximum unsupported spans are not generalized.

Chemical Resistance and Water-Hammer Considerations

GRP piping is generally constructed with an internal C-glass liner designed to provide excellent chemical resistance, but the rest of the pipe wall is reinforced with E-glass which has less chemical resistance and is protected by a relatively heavy layer of epoxy resin on the pipe exterior. Chemical resistance testing performed by most manufacturers with epoxy-fiberglass pipe specimens filled internally with gasoline, jet fuel, kerosene, oil, water. and salt water indicate acceptable stress retention and recommended service with all of these fluids at elevated temperature. However, since resistance of the pipewall to external chemical attack can not be determined from internal chemical resistance, tests were conducted at DTNSRDC with ring and cube specimens cut from GRP pipe and molded fittings to determine external splash resistance to JP-5, DFM, ND fuels, phosphate ester type hydraulic fluid, and simulated seawater (conforming to ASTM D-1141-52). After immersion of the specimens in each of the fluids at room temperature for a period of 75 days, there were no significant changes in dimension, weight, color, or hardness of the specimens tested. Only a slight dulling of the exterior gloss of specimens immersed in phosphate ester type hydraulic fluid was observed. Although conclusions could not be drawn from these tests regarding actual strength of the pipe wall after exposure to the fluids considered. no significant effects would be expected from the standpoint of splash resistance.

The effects of water-hammer in a piping system must be considered as part of any new design or modification to existing systems. A brief analysis comparing the effects of water-hammer in piping systems constructed of aluminum and GRP, showed that the pressure surge due to instantaneous valve closure in a Schedule 10 aluminum piping system was 2.2 to 3 times that in a GRP system under identical conditions. The lower pressure surge with GRP piping is primarily due to its lower modulus of elasticity. The fatigue strength of aluminum piping ranges from 1.2 to 2.3 times that of a GRP pipe depending on the alloy and temper selected. Therefore, from the standpoint of water hammer, the GRP system can be expected to perform as well as, or better than, an aluminum piping system in the same application.

MARINE FOULING

Marine fouling can occur on any nonprotected surface; that is. any surface that will not leach metal salt or other agents toxic to marine life. Aluminum, titanium. steel. plastics. and GRP materials are all nonprotected and, therefore, fouling can be expected to take place in piping made of these materials. Severe marine fouling can also occur in copper-nickel piping systems under certain conditions although alloys with high copper content are considered protected on a relative scale of fouling resistance.

Fouling experiments conducted by BASIL [10] with polyester and phenolic glass-reinforced test panels revealed no evidence of damage as a result of fouling attachment which occurred after a 14-month exposure in seawater. In quiet seawater, the panels acted as good collectors of marine organisms. However, the fouling that occurred was easily cleaned by mild scraping, and there was no evidence of attack by marine borers or other marine life. GRP piping fabricated with epoxy resins is expected to foul in the same manner under quiet seawater conditions. The resin is considered inert to marine life offering no food value and producing no toxic effects. Current seawater applications of GRP epoxy piping include cooling water lines for offshore drilling platforms in the Gulf of Mexico, seawater intake and outlet piping for power plant applications, and air conditioning cooling lines for Carribean resort hotels. Drilling platform operators report no fouling problems in 12-inch diameter seawater circulating lines operating continuously for approximately five years at maximum velocities of 5ft/sec. Fouling does occur. however. in lines that are shut down for l-month periods while heat exchangers are being cleaned. Power plant operators report reduced oyster attachment with GRP piping compared to previous experience with steel piping. In all cases, reduced fouling with GRP piping is attributed to the very smooth interior walls of the pipe which provide a poor surface for firm attachment by mussels, barnacles, and other marine life.

The most effective state-of-the-art solution to potential fouling problems in seawater circulating systems that appears practical for shipboard application is electrolytic hypochlorination. This process involves generation of sodium hypochlorite (NaOCl) by electrolytic decomposition of seawater. As seawater flows through an electrolytic cell, a current passes through the water from anode to cathode surfaces generating a dilute NaOCl solution. This solution can be used at very low concentrations as an effective chlorinator for control of water borne organisms. Sodium hypochlorite generators have been designed specifically for shipboard use and are currently used in commercial ships. In a shipboard electrolytic chlorinating system, a relatively small flow of water is taken from the circulating pump discharge and passed through the generator which converts some of the salt in the seawater to NaOC1. The NaOCl seawater solution is then returned to the sea chest or pump inlet and mixed with the main flow to control fouling through the entire system. Continuous chlorination at very low levels, which will discourage, but not necessarily kill, marine organisms entering a seawater system through screens or filters, appears practical for shipboard application. Investigations done by SCHREITZ [11] indicate that continuous chlorination as low as 0.25ppm can completely eliminate all marine growth. and that concentrations of about 0.50ppm would be a suitable norm for practical application.

The use of electrolytic chlorination is particularly attractive with GRP piping. since a nonmetallic pipe wall eliminates the possibility of corrosion damage by stray currents.

Another approach to solution of potential fouling problems which may become practical in the near future involves the development of low-leaching, nonpolluting, organometallic antifouling polymers such as those described by DYCKMAN and MONTEMARANO [12]. Future work may make it possible to use organometallic resins in fabrication of an inherently nonfouling GRP pipe.

EROSION RESISTANCE

The erosion resistance of GRP pipe, fittings. and joint adhesives to high velocity seawater is being investigated in two phases. The first phase involved small scale experiments with jet-impingement test apparatus. The apparatus consisted of a mixing chamber *or* header from which aerated seawater was distributed to a number of nozzles. from which jet streams of seawater impinged separately upon the test specimens. The specimens were immersed in seawater during the tests and mounted perpendicular to the jet streams. Flat 1/2-inch by 3-1/2-inch specimens of the filament-wound pipe, molded fittings, and cast adhesive were subjected in duplicate pairs to jets of natural seawater saturated with air at velocities of 15, 25, 35, and 45ft/sec for 60 days. After the exposure there was no detectable erosion damage on the exposed surfaces of any of the specimens.

The second phase of the erosion investigations is currently being planned and will involve 2-inch diameter piping mock-ups incorporating GRP elbows. tees, and couplings. Flanged GRP pipe spools will be located upstream and downstream of throttling valves and fittings in these configurations through which natural seawater will be pumped at relatively high velocities for approximately one year. Periodic nondestructive inspections will be made to determine the extent and rate of accumulation of turbulence induced erosion.

SHOCK PERFORMANCE

The high-impact shock performance of GRP pipe assemblies is currently being investigated. Results of experiments conducted to date with 1-inch diameter flanged pipe sections showed no joint or pipe failures until test loading exceeded the ultimate strength of the pipe wall. In torsion, preliminary results show that joints fail before the pipe at high stress levels due to the stiffness of the composite pipe in torsion (reinforcing fibers in the candidate test pipe were wound at an angle of approximately 55° to the pipe axis). Shock tests in accordance with MIL-S-901C are also being conducted with 3-. 6-. and 12-inch diameter assemblies. Results from tests completed to date with 3-inch diameter assemblies indicate the possible need for flexible couplings at certain locations (such as bulkhead penetrations) where severe torsional loading can be developed under shock conditions. Various bulkhead penetration techniques, flexible couplings, and pipe support methods will be investigated to enhance shock performance.

NONDESTRUCTIVE JOINT INSPECTION TECHNIQUES

Preliminary investigations were conducted by ultrasonic and optical techniques to determine the feasibility of shipboard nondestructive detection of various defects in GRP adhesive bonded pipe joints.

Test sections with molded and filament wound fittings were fabricated with joints simulating areas with no adhesive, adhesive stained areas, disbonds, incorrect taper angles, and contaminated bonding surfaces. Results indicate that detection of many of these defects by ultrasonic pulse echo techniques is feasible. The best inspection sequence included a high frequency examination of near surface reflections of a bonded joint devoid of water, followed by a low frequency examination of far surface reflections with the joint tilled with water. Optical techniques did not appear to offer any promise of detecting disbonds or contaminated bonding surfaces and they could not be used to detect voids unless adhesives with much greater optical opacity were employed. Although feasibility of the ultrasonic pulse echo technique to detect various joint defects has been demonstrated, further laboratory efforts would be required before actual field implementation can be achieved.

SUMMARY

1) EXTREMELY LIGHTWEIGHT — Weight comparisons made on a per foot and installed system basis showed that GRP piping was the lightest, corrosion-resistant piping material currently available commercially in the 1- through 6-inch size range.

2) RELATIVELY LOW COST — Cost comparisons showed that GRP piping systems will be less expensive than copper-nickel. titanium. stainless steel, and aluminum alloys that may be considered for seawater and freshwater applications.

3) RELATIVELY SIMPLE, LOW-COST INSTALLATION — Installation of a full-scale GRP system at DTNSRDC has revealed that pipe tapering equipment can be automated, and, after a few hours of instruction, the piping can be efficiently and properly installed by regular pipe-titters having no previous experience with the material.

4) CORROSION RESISTANT — GRP piping is internally chemically resistant and externally splash-resistant to seawater, freshwater, fuels, and oils normally encountered in the shipboard environment.

5) CONTROLLABLE SURFACE FLAMMABILITY — Results of radiant panel surface flammability tests with sections of *unprotected* GRP pipe showed an average flame-spread index of 79 which could be reduced to acceptable shipboard levels of 25 or less with addition of intumescent paints. mastic coating compounds. or lightweight ceramic insulation.

6) ACCEPTABLE SMOKE LEVELS — Results of experiments using National Bureau of Standards smoke

chamber apparatus revealed an average maximum specific optical density of 286 under flaming conditions for ***unprotected*** GRP pipe specimens. The addition of intumescent epoxy paint reduced the optical density to 210. This reduced level is considered low relative to plastic materials currently used in naval shipboard service. For example, polyvinyl chloride piping used in nonvital shipboard applications has a smoke density rating of approximately 525 which is 2-1/2 times that of GRP protected with intumescent paint. The smoke level of 210 is below the level of 250 specified in MIL-P-001528F (SHIPS) of 30 May 1973 for plastic foam materials now used for piping insulation aboard naval surface ships.

7) NO HAZARDOUS CONCENTRATIONS OF TOXIC GASES — Analysis of potentially toxic gases including CO, CO_2, HCl, HCn, HF, MH_3, NO_2, and SO_2 generated during smoke chamber tests showed no hazardous concentrations when compared to personnel exposure limits established by BUMED INSTRUCTION 6270.3F of 15 August 1972. Further tests with intumescent coatings are planned.

8) EXCELLENT FIRE RESISTANCE UNDER FLOWING AND STAGNANT WATER CONDITIONS — Flowing water fire tests under both laminar and turbulent flow conditions at 100 lb/in^2 internal pressure revealed that ***unprotected*** GRP piping with molded fittings and bonded joints remained functional for more than ***one*** hour in a simulated shipboard fire. In stagnant water fire tests at 150 lb/in^2 internal pressure, ***unprotected*** GRP pipe, molded fittings, and bonded joints remained functional for the full 1/2-hour fire test and outperformed both the aluminum and silver-brazed copper-nickel systems under these conditions. These tests also showed that some of the filament wound "in-line" GRP fittings (as they are currently produced by one manufacturer) are not thick enough to provide the thermal insulation required to protect bonded joints exposed to full axial pressure loading. The use of GRP piping in systems conveying combustible liquids requires special considerations and precautions from the standpoints of fire protection and static electrical build-up.

9) IMPROVED FIRE PERFORMANCE RELATIVE TO ALUMINUM UNDER DRY-PIPE CONDITIONS — Tests with unprotected dry-pipe assemblies showed that with both GRP and aluminum failure can be expected within two minutes. However, in these tests aluminum pipe will fail catastrophically, while GRP exhibits a much safer, gradual mode of failure. Under dry-pipe conditions, the silver-brazed copper-nickel system fails within ***four*** minutes.

10) **PROTECTIVE MEASURES IMPROVE PERFORMANCE UNDER DRY CONDITIONS** — Extremely lightweight protective measures including intumescent paints, intumescent mastic tapes, composite protective sleeves, and aluminized ceramic insulation were shown to provide from 1 minute to 10 minutes of additional protection with dry GRP pipe. The protective systems investigated were limited to those which would not increase the weight of the piping above that of bare Schedule 10 aluminum piping.

11) **SAFE FAILURE MECHANISM** — In the cyclic fatigue tests, 24 assemblies were cycled (fully reversed stress) to failure. In all cases, failure occurred in the pipe wall as weeping which very slowly increased with continued cycling. This is considered a safe failure mechanism as compared to fracture or joint separation.

12) FITTINGS AND BONDED JOINTS OUTPERFORMED PIPE UNDER CYCLIC FATIGUE CONDITIONS — Investigation of cyclic fatigue characteristics of GRP pipe, fittings, and joints with 1-, 3-, and 6-inch diameter assemblies under both low (5cpm) and high frequency (10Hz to 25Hz) conditions showed that joints and fittings operate at relatively low stress levels, and consequently, will not fail before the GRP pipe itself.

13) MECHANICAL PROPERTIES DEFINED FOR SHIPBOARD APPLICATION — Experiments completed with 1-, 3-, and 6-inch diameter GRP assemblies measured properties of the pipe wall (elastic moduli and Poisson's ratio) in the axial, hoop, and 45° directions. The specimens were subjected to tension, compression, bending, torsion, and internal pressure.

14) S-N CURVES DEVELOPED AS **DESIGN GUIDELINES** — All cyclic fatigue assemblies were instrumented with gages to measure strains which were converted to stress levels using elastic moduli and Poisson's ratios previously discussed. STRESS versus CYCLES TO FAILURE was plotted for each assembly, and the resulting S-N Curve provides a design guideline for safe shipboard application.

15) **EXCELLENT JOINT QUALITY** — A full-scale heat exchanger test facility was fabricated at DTNSRDC using 3-, 4-, and 12-inch-diameter GRP piping materials. The installation was made by pipefitters having no previous experience with the material. The completed system contained over 120 bonded joints, and no failures were experienced after initial pressurizetion or subsequent operation.

16) GOOD RESISTANCE TO PHYSICAL ABUSE — Axial tension and cyclic fatigue tests conducted with notched and scarred GRP pipe and fittings provide evidence that the material exhibits good resistance to external damage.

17) MARINE FOULING CONTROLLED WITH ELECTROLYTIC HYPOCHLORINATION — Continuous chlorination at very low levels which will discourage, but not necessarily kill, marine organisms entering a seawater system through screens or filters, appears practical with commercially available shipboard electrolytic hypochlorinator systems.

18) SHOCK **PERFORMANCE** — **In tension and bending preliminary results indicate** no joint or pipe failures until test loading exceeded the ultimate strength of the pipe wall. Flexible couplings may be required to control torsional loadings on bonded joints.

19) EROSION RESISTANCE — Jet impingement tests on small GRP specimens showed no erosion damage after 60 days exposure. Full scale tests are being planned.

20) JOINT INSPECTION — Feasibility of ultrasonic joint inspection has been demonstrated. Optical techniques do not appear promising.

CONCLUSIONS

Results of investigations and tests to date have provided encouragement. not only for application of GRP piping systems for high performance weight critical craft, *but also* for general applications throughout the entire naval and commercial surface fleet in seawater and freshwater systems. By ***eliminating corrosion*** problems which have plagued the surface fleet for decades, significant savings in replacement costs and maintenance time are possible.

The current investigations with several diversified GRP pipe, fitting, and joining concepts will provide the performance criteria necessary to develop a military specification ensuring required characteristics for general shipboard service. Through the cooperation of Industry a workable and viable specification should be produced which will help advance the state-of-the-art of GRP piping material and permit this material to find its natural place in shipboard applications.

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The Authors' investigation of Glass Reinforced Plastic (GRP) Pipe complements one of the research projects being managed by Todd Shipyards Corporation for the National Shipbuilding Research Program — a Program developed by the MARITIME ADMINISTRATION (MARAD) and the Ship Production Committee of the Society of Naval Architects and Marine Engineers, it features management of pragmatic research projects, on a cost sharing basis, by certain shipbuilders in behalf of the entire U.S. shipbuilding industry. The project's goal is to facilitate increased use of cost-effective plastics and reinforced plastics in commercial ship construction. The end product is a Manual for shipbuilders, now being edited, which:

- Contains fundamental knowledge about plastics.
- Points out advantages and limitations.
- Explores selected applications which have the potential for greater productive use.

At the very beginning the researcher, DeBell & Richardson; Inc., reported that over 50 million feet of GRP pipe is produced annually in the United States for chemical plants, oil fields, et cetera, and that there is little usage in ships. This is attributed to the limited knowledge possessed by ship designers, owner, regulators, and builders regarding the use of GRP pipe in specific applications. Therefore, National Steel and Shipbuilding Company (NASSCO) was engaged to perform the special study, referenced by the Authors, which focused on design, installation and cost considerations. The Authors' work contributes substantially to the knowledge needed to create assurances for safety that the U.S. COAST GUARD and the American Bureau of Shipping must have. Therefore, the Authors' findings, which were then available, were included in the same volume which reported NASSCO,s results to the U.S. shipbuilding industry.

From these activities, sponsored by different agencies of the Government and the shipbuilding industry, a necessary general understanding of plastics is being disseminated. Designers are becoming aware that by specifying particular compounds they can achieve one or more of the following properties, among others:

- Impact resistance (toughness).
- Chemical resistance.
- Electrical resistance (or conversely conductivity through the use of additives or by metal plating).
- Self-extinguishing (through the use of additives; over 4.5 billion pounds of self-extinguishing plastics which comply with codes for buildings. appliances, aircraft, etc. are now in use).
- High Young's modulus (through filament winding, cross laminating, or use of high modulus fiber).

Managers are becoming aware that the use of GRP permits reductions in *all* of the resources for piping systems, i.e., materials, manpower, facilities and time. Further it is especially notable that the processes for the manufacture and installation of GRP pipe are less energy intensive and permit employment of less skilled craftsmen. These are important mobilization considerations.

The research performed for applications in naval ships and that for commercial ships led to the same conclusion, i.e., a standard is prerequisite for the greater use of GRP pipe. Development of a standard has already been suggested in a manner like that for electric cable which is a joint USCG/MARAD sponsored project about to be assigned to Todd for implementation.

Similarly, such effort should recognize that a large applicable market already exists outside the marine community. Thus, the research should incorporate ***four*** separate tasks as follows:

1) DEVELOP A STANDARD — It should: a) apply to the broad category of reinforced thermosetting resin pipe (RTRP) and fittings, b) list specific sizes and dimensions, c) provide for safety, installation, and service requirements by specifying performance criteria against which any RTRP can be compared to determine acceptability, and d) include the rationale for each performance category.
2) SURVEY FOR COST EFFECTIVE RTRP — This task, which can progress simultaneously, is intended to produce a list of types that could be productively used in shipbuilding. Each type should exist in a current market or be producible with existing manufacturing capabilities.
3) DEVELOP A TEST SPECIFICATION — lt should consist of detailed descriptions of tests and test criteria separated into categories which match the performance categories contained in the Standard.
4) TEST AND EVALUATE — This task would bc the basis for improving the Standard and/or Test Specification as necessary. The list of RTRP types determined to be acceptable in accordance with the final revision of the Test Specification would be an additional end product.

It makes sense to develop a RTRP Standard and Test Specification that can be used for both commercial and naval shipbuilding. *But more is needed.* They must be accompanied by *specific* proposals for their incorporation in the USCG administered Code of Federal Regulations, American Bureau of Shipping Rules, and specifications for building naval ships.

Until allowed usage of RTRP in ships is further definitized, there will be continued reluctance by pipe systems designers to risk new applications. There will be continued disinterest by the RTRP manufacturing industry because shipbuilding is a relatively small market characterized by uncertainty about the increased potential for plastics. In commercial shipbuilding, productivity impacts on the "bottom line". In naval shipbuilding, productivity impacts on military readiness.

APPENDIX D

SUGGESTED SPECIFICATIONS FOR "FIBERSHEEN" SHOWER STALLS FOR THE SHIPBUILDING INDUSTRY AS MANUFACTURED BY THE THEODORE EFRON MFG. CO., CHICAGO, ILLINOIS

Contractor shall furnish and install "fibersheen" institutional glass fiber reinforced polyester shower stalls as per drawings complete with dome.

GENERAL DESCRIPTION

All units shall be manufactured in strict accordance with Commercial Standard CS222-59 and shall be plainly marked with such, indicating the manufacturer's trade name permanently marked on the inside of the front curb in the shower floor area. Commercial Standard CS 222-59 shall be used as a minimum manufacturing guide only. The stall will consist of one-piece, gel coated, seamless floor and wall area.

GLASS CONTENT

All units shall have a minimum of 33⅓% glass fiber content (by volume) which shall be applied by the spray up lamination method.

RESIN

Shall be self-extinguishing contact molding type and the flame retardancy shall be within 1" line-out time of 8-16 seconds. ASTM D 635-56T.

Flexural strength - when laminated with glass	38,000 psi
Modulus of Elasticity	**1.30×10^6 psi**
Tensile Modulus	1.24×10^6 psi
Compressive strength flat wise	61.800 psi
Barcol Hardness	61
HTL 15 rating	72

REINFORCING

All units shall be reinforced to receive shower fixtures and accessories as prescribed by the architect.

FOAM

The bottom of all units shall have polyurethane foam applied for the purpose of insulation, vapor barrier and" sound deadening.

Moisture vapor transmission	Closed cells percent 90 min.
Tensile strength (min.)	ASTM D 1623-59T
parallel to rise	50 psi @ 2.5% elongation
perpendicular to rise	10 psi @ 4.5% elongation
Compression strength (min.)	ASTM D 1623-59T
at yield paralleI to rise	75 psi @ 6% deflection
perpendicular to rise	60 psi @ 6% defection
Flammability	ASTM D 1692-59T
Classification -	no further burning beyond
self extinguishing	**¼" past first 1" mark**

GEL COAT

Gel coat thickness minimum 0.020 to 0.025

Gel coat shall be white, flame retardant, bathroom fixture quality as approved by SPI and equivalent to Cook #514. Barcol Hardness: Dial reading average top 50.5- bottom 47.6

APPENDIX E

Flammability Tests and Guidelines

Summary of Some of the Major Flammability Tests

Test	Matcrials	Use	Procedure
Ignition tests:			
ASTM D 2863 oxygen index test	All	New test that gives good relative ranking of materials	Sample is burned in a measured mixture of O_2 and N_2 in which percentage of oxygen is decreased to determine minimum amount necessary to support combustion
UL hot-wire ignition	Plastics	Plastics parts in electrical applications certified by UL	Bar-shaped sample is wrapped with resistance wire which is heated electrically to red heat. Time for sample to ignite is measrcd
UL high-current arc ignition test	Plastics	Plastics parts in electrical applications certified by UL	Elertrodcs resting on samplc arc rcpeatedly moved together until they are and then apart till arc is ruptured. Number of ruptures required to ignite sample is recorded
UL high-voltage arc ignition test	Plastics	Plastics parts in electrical applications certified by UL	Two electrodes rest on surface of sample 4.0 mm apart. Current is supplied to cause a continuous arc. Time required for ignition is measured
ASTM D 2859 methenamine pill test	Carpets and floor coverings	For compliance with DOC standard for carpets exceeding 24 ft^2	Methenamine pill is ignited on sample and allowed to burn out. Burned area is measured (test also measurcs flamc propagation: see below)
Flame propagtstion tests:			
ASTM D 635, FTM 2021	Plastics sheet	Burn rate of 2.5 in./min for approval under BOCA, SPI Model Code. and other building codes	Horizontal sample is exposed to bunsen-burner flame for 30s and Allowed to burn until fire goes out or sample is consumed. Rate is mensurcd in in., min
ASTM 1692, UL subject 94	Plastics foams	Testing foams for building and furniture applications	Horizontal sample is exposed to bunsen-burner flame for 60s. In .UL 94, cotton is planed under sample. Burn rate,, is mensured and flaming droplets must not ignite cotton
ASTM E 84, UL 723, NFPA 255. 25-ft tunnel test	All	Most widely used test for building materials. Model codes require a rating of 25 for interior finishes in stairwells, 75 in exit areas, and from 75 to 25 in rooms	Sample is mounted along ceiling of 25-ft-long tunnel and ignited by burner at front end of tunnel. Burn distance is noted, and compared with red oak, which is set at 100 (test also measures heat contribution and smoke generation; see below)
UL subject 94 test for self-extinguishing polymers	Plastics sheet	Materials in applications certified by UL	Vertically oriential sample is exposed to a bunsen-burner flame for 10 s. If burnig censes in less than 30 s, a second 10-s application of flame is required. Flaming droplets are allowed to fall on cotton. If average burning time is less than 5 s and drips do not ignite cotton, material is self-extinguishing, group 0. If time is less than 25 s and drips do not ignite cotton, material is rated self-extinguishing group I, and if cotton is ignited, material is self-extinguishing group II
MVSS302 horirzontal burn test	Afi	Adopted by Department of Transportation for all materials used in automotive interiors	Horizontal specimen is ignited a 15-s applicntion of a bunsen-burner flame. When flame has burned 11/2 in. of the sample., time is measured until material ceases to burn or until burning has procrcssed 10 in., and ratc must not exceed 4 in. /min to pass
FAA vertical test	AIi	Required by FAA for materials including surface finishes and decorative components of aircraft crew and passenger compartments	Bunsen-burnmr flamc is applied to a vertical specimen for 60 s. Flanner time. burn length, and burn time of drips are notes. To pass, burn must he less than 6 in., flame time must not exceed 15 s, and drippings must go out before 3 s
FAA horizontal test	All	Reqttircd by FAA for components of aircraft	Same conditions as abovc except samples arc horizontal. Maximum acceptable burn rate is 2 1/2 in. /min for acrylic windows. instrument assemblies. seat belts. and shoulder harnesses. Small molded parts are acceptable if burn rate is less thins 4 in. ,'min

(continued)

Summary of Some of the Major Flammability Tests (continued)

Test	Materials	Use	Procedure
Fire endurance:			
ASTM E 119, UL 263, MFPA 251 fire endurance teat	AU	Testing fire endurance of walls. floors, ceilines. roofs. cte.. required by various building codts	Fill-sized wall section is used as a partition in a room-sized furnace. In ASTM E 119 one side of the partition is exposed to gas fire with ternperaturcs reaching 1000°F at 5 min, 1300°k' after 10 min. 1700°F after 1 h, and 2000°F after 4 h. To pass. temperature on the far side of the specimen should not exceed 250°F. Similar tests specify different temperatures and time limits
Bureau of Mines flame penetration	Plastics foams	materials used in mines	Time required to burn through a 1-in.-thick layer of foam exposed to a continuous flame from a propane torch temperature of 2150°F
Heat contribution, factory mutual calorimeter	All	By insurance underwriters to test building components	Sample is burned in a gasoline-fired furnace and time-temperature curve is recorded. A non. combustible sample is substitutcd and timc-temperature curve is reproduced using propane. Heat added to reproduce curve gives value of sample
Smoke generation:			
ASTM D 2843, Rohm & Hans XP2 smoke density chambcr.	Plastics	Testing for complince with buid-ing codes	Sample is placed in a chambce and is ignited by a propane flame. and smoke density is measured by a photocell across a horizontal 12-in. light path. Most building codes permit materials if maximum light absorption is less than 50%. Uniform Building Code accepts UP to 75%
NBScbamber	All	FAA for aircraft components (proposed)	Similar to above except that a radiant-heat sourcc is used and the optical path for measurement is vertieal and longer than in the ASTM chamber. Conditions in this chamber are thought to approximate more closely conditions in actual fires

In addition ASTM E162-67 describes a Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat . Energy Source.

Urban Mass Transportation Authority
Guidelines for Flammability and Smoke pecifications*

Materials	Test Method	Requirements
Flammability :		
Cushioning, thermal and acoustical forms	**ASTM El 62-67 radiant panel test (modified for sample mounting and burner flame)**	**25 Is (flammability index), No flaming drips allowed. Fire-resistant properties must be "permanent. ''**
Wall and ceiling panels	**ASTM E162-67**	**35 Is. No flaming drips.**
Plastic glazing and lighting diffusers	**ASTM E162-67**	**100 Is.**
Upholstery	**F&l regulation 25.853 vertical test (with some differences in limits)**	**10-see burn time and 6-in. burn length , after flame -source removal. No flaming drips allowed.**
Carpeting (including underlay, if used)	**NBSIR 74-494 (NBS flooring radiant** panel test)	**O. 6 w/ cm2minimum critical radiant flux**
Elastomers	ASTM C542-71a	Pass test. No flaming drips allowed.
Smoke emission :		
Upholstery, air ducts, thermal insulation and insulation cover	NBS technical note 708 or NFPA 258-T using NBS smoke chamber	100 Ds (optical density within 4 minutes after start of test.

(continued)

*Based on guidelines (TSC-75-LFS-5) issued Aug. 22. 1975 by Transportation Systems Center, Cambridge, Mass. Applies to all types of mass-transit vehicles purchased with UMTA funds.

Urban Mass Transit Authority
Guidelines for Flammability and Smoke Specifications (continued)

All other materials (e*-eluding seat cushioning, electrical insulation and carpeting)	As abo"ve	100 Ds within 90 seconds; not to exceed 200 Ds within 4 minutes
Electrical insulation	Being developed	Recommendation: "Avoid heavy -smoking materials such as PVC and chlorinated, sulfonated poly-ethylene. "
Toxic-gas emission	Deferred pending de-velopment of standards	

APPENDIX F

"Anti-Friction Plastic for Launchways" from LICENSINTORG-SOVIET INVENTIONS NEWSLETTER ISSUE #18.

The new plastic material is basically intended for ensuring proper slipping of ships when the latter are launched from the inclined building slip, and helps to avoid appliation of mined and organic coating.

The material is hardly-fiammable, features biological resistance as well as resistance to the effects of sea and river water anti-friction properties of the material practically do not depend on the ambient temperature thus ensuring proper slipping of ships within a temperature range of -30"C through +40"C. The strength of the material allows to increase by several times specific loads at the time of slipping and ensures its multiple application (at least 30 shippings). The cost of the material is 10 times less than that of the. mineral coating.

Employment of the herein-described material provides for a substantial saving due to reduced labour consumption in preparing the launching slip, saving in coating materials, elimination of some launching operations, elimination of the necessity to install boat ports and cells for dewatenng the submerged portion of the slipping dock. The herein-offered plastic material features the following physical and mechanical properties:

Specific weight, .g/cu cm	0.91-0.93
Tensile strength, kg/sq cm:	
at compression	56-64
at elongation	50-55
at static bent	70-80
Impact viscosity, kg-cm/sq cm	6.0-6.5
Brinnel hardness, kg/sq cm	8.0

The following guidelines for flammability specifications were recently issued by I. Litant, Transportation Systems Center, U.S. Department of Transportation for application to combustible materials used in transit systems. These guidelines are revised periodically to reflect the certification of better standards and improved materials used in transit systems. Your comment is always solicited. The guidelines below supercede TSC-75-LSF-4.

FLAMMABILITY GUIDELINES

OFFERED BY THE DEPARTMENT OF TRANSPORTATION

GUIDELINES FOR FLAMMABILITY AND SMOKE EMISSION SPECIFICATIONS - TSC-75-LFS.5

Flammability

Scope-This specification relates to all combustible materials used in a transit system, and includes seat cushions, upholstery, flooring, carpeting, wall and ceiling panels, plastic glazing and lighting diffusers, thermal and acoustical insulation, and electrical insulation.

- Seat cushions and thermal and acoustical foams shall be capable of passing the ASTM E 162-75 Radiant Panel Test with a flame propagation index not exceeding 25. Additional provisions are as follows: (a) there shall be .no flaming running or dripping, (b) wire mesh screening shall be used (as per section 5.9.2), (c) a 6-inch long pilot flame (burner tip situated 11/4 inch beyond the frame to prevent extinguishment), (d) aluminum foil shall be used to wrap around the back and sides of the specimen.

Furthermore, the fire-resistant properties of the foam shall be demonstrated to be permanent.

- Wall and ceiling panels shall be capable of passing the ASTM E 162-67 Radiant Panel Test with a flame propagation index not exceeding 35, with the additional provision that there shall be no flaming drippings.

- Upholstery materials shall be tested by FAA Regulation 25.853 vertical test, Appendix F(b), with the following modifications: a) the average flame time after removal of the flame source may not exceed 10 seconds, b) burn length shall not exceed 6 inches, c) flaming drippings shall not be allowed, d) fabrics that must. be machine washed or dry cleaned must meet the requirements of 1.1.3a, b, and c, after leaching according to Federal Test Method 191b Method 5830, or after dry cleaning according to AATCC-86-1968. Fabrics that cannot be machine washed or dry cleaned must be so labeled and pass the leaching test as well as 1.1.3a, b, and c after being cleaned as recommended by the manufacturer.

- Carpeting shall be tested with its padding, if latter is to be used, and shall be capable of passing the NBS Flooring Radiant Panel Test, NBSIR 74-495 with a minimum critical radiant flux of 0.6 watts/cm .

- Plastic windows and lighting diffusers shall be capable of passing the ASTM E 162-67 Radiant Panel Test with a flame propagation index not exceeding 100.

- Flooring shall be capable of withstanding the requirements of ASTM E 119 when exposed for 15 minutes to 1400°F on its underside surface.

- Elastomers shall be capable of passing the requirements of ASTM C 542-71a, with lhe added requirement that flaming drippings shall not be allowed.

- Electrical insulation

  a) Wires for control, auxiliary circuits, speaker, public address, intercom system and the Iike shall be tested according to I.P.C.E.A. S-19.81, paragraph 6.19.6 or Underwriters Laboratory Standard 62. The exception to these standard procedures is that the 15 second flame exposure and rest cycle is changed to read as follows: In any case, the flame is not to be reapplied until any flare. ing which is caused by the previous application ceases of its own accord even though the time interval be. tween applications may exceed 15 seconds.

(continued)

There is *no* standard test method for assuring circuit integrity of this type of wire during and after exposure to flame. However, it is highly desirable that an insulating char or residue remain on the wire in order to maintain continuity of service.

b) High voltage cable shall be tested according to the IEEE Standard 383-1974. A further provision of this test is that circuit integrity continue for 5 minutes after the start of the test.

Smoke Emission

Scope-This specification relates to all combustible materials as listed in 1.1, with exceptions as noted.

- All materials shall be tested ***for*** smoke emission in accordance with the National Bureau of Standards Technical Note 708, “Interlaboratory Evaluation of Smoke Density Chamber;’ December 1971, Appendix II, “Test Method for Measuring the Smoke Generation Characteristics of Solid Materials:’ dated September 1971, or NFPA No. 258-T, “Smoke Generated by Solid Materials” (1974). The optical density, Ds, in both flaming and non-flaming modes, determined in accordance with the test, shall have the following limits:

  a. For upholstery, air ducting, thermat insulation and insulation covering, the Ds may not exceed 100 within4 minutes after start of the test.

  b. For all other materials, with the exception of foam seat cushioning, electrical insulation, and carpeting the Ds may not exceed 100 within 90 seconds after the start of the test, and may not exceed 200 within 4 minutes after the start of the test.

Test procedures for electrical insulation will be pubished as soon as test procedures have been finalized. In the interim, known heavy smoking insulation such as PVC and chlorinated, sulfonated polyethylene should be avoided.

Toxic Gas Emission

At the present time, there are no acceptable toxicity standards that can be applied to the types of materials discussed above. It is hopeful that such standards will soon become available, if only as preliminary standards.

Your comments are of interest. Please send them to:

FIRELINE
P. O. Box 66
Menlo Park, CA 94025

Fireline will be pleased to compile and relay your comments to Mr. Litant 's attention.

APPENDIX G

References for Future Reading

1. Modem Plastics Encyclopedia (published annually).

2. Polymer Processes - By Schildenecht - Interscience Publishers, N. Y., N.Y.

3. Encyclopedia of Polymer Science and Technology - Interscience Publishers, N. Y., N.Y.

4. Source Book of the New Plastics - H. R. Simonds - Reinhold Publishing, N. Y., N.Y. Volumes I and II.

5. Advanced Fibrous Reinforced Composites - Society of Aerospace Material and Processing Engineers - Published by Western Periodicals Company, North Hollywood. California.

6. Polymer Blends and Composites - H. A. Manson & L. H. Sperling, Plenum Press, N. Y., N.Y.

7. Manufacture of Plastics, W. M. Smith - Reinhold Publishing, New York. N.Y.